

UC-NRLF



\$D 12 784

No. 70.

9 Cents.

EXPLOSIVE MATERIALS

The Phenomena and Theories of Explosion

AND THE CLASSIFICATION, CONSTITUTION
AND PREPARATION OF EXPLOSIVES

BY

COLONEL JOHN P. WISSER

COAST ARTILLERY CORPS

Military Attache to the American Embassy in Berlin

Second Edition, Revised and Enlarged

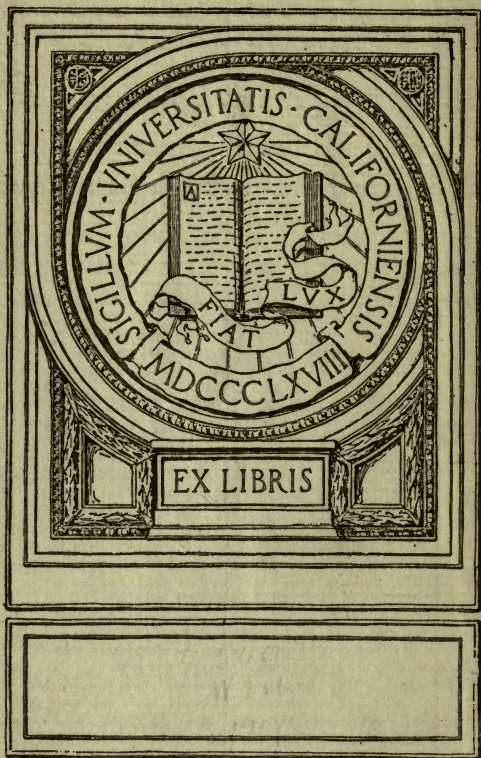


NEW YORK

D. VAN NOSTRAND COMPANY

23 MURRAY AND 27 WARREN STREETS

1907



from the French of A. Mallet. Second edition, revised with results of American Practice, by Richard H. Buel, C.E.

***No. 11. THEORY OF ARCHES.** By Prof. W. Allan.

No. 12. THEORY OF VOUSOIR ARCHES. By Prof. Wm. Cain. Third edition, revised and enlarged.

- No. 13. GASES MET WITH IN COAL MINES.**
By J. J. Atkinson. Third edition, revised and enlarged, to which is added The Action of Coal Dusts by Edward H. Williams, Jr.
- No. 14. FRICTION OF AIR IN MINES.** - By J. J. Atkinson. Second American edition.
- No. 15. SKEW ARCHES.** By Prof. E. W. Hyde, C.E. Illustrated. Second edition.
- No. 16. GRAPHIC METHOD FOR SOLVING**
Certain Questions in Arithmetic or Algebra. By Prof. G. L. Vose. Third edition.
- *No. 17. WATER AND WATER-SUPPLY.** By Prof. W. H. Corfield, of the University College, London. Second American edition.
- No. 18. SEWERAGE AND SEWAGE PURIFICATION.** By M. N. Baker, Associate Editor "Engineering News." Fourth edition, revised and enlarged.
- No. 19. STRENGTH OF BEAMS UNDER**
Transverse Loads. By Prof. W. Allan, author of "Theory of Arches." Second edition, revised.
- No. 20. BRIDGE AND TUNNEL CENTRES.** By John B. McMaster, C.E. Second edition.
- No. 21. SAFETY VALVES.** By Richard H. Buel, C.E. Third edition.
- No. 22. HIGH MASONRY DAMS.** By E. Sherman Gould, M. Am. Soc. C.E. Second edition.
- No. 23. THE FATIGUE OF METALS UNDER**
Repeated Strains. With various Tables of Results and Experiments. From the German of Prof. Ludwig Spangenburg, with a Preface by S. H. Shreve, A.M.
- No. 24. A PRACTICAL TREATISE ON THE**
Teeth of Wheels. By Prof. S. W. Robinson. Third edition, revised, with additions.
- No. 25. THEORY AND CALCULATION OF**
Cantilever Bridges. By R. M. Wilcox.
- No. 26. PRACTICAL TREATISE ON THE PROP-**
erties of Continuous Bridges. By Charles Bender, C.E.
- No. 27. BOILER INCRUSTATION AND CORRO-**
sion. By F. J. Rowan. New edition. Revised and partly rewritten by F. E. Idell.
- *No. 28. TRANSMISSION OF POWER BY WIRE**
Ropes. By Albert W. Stahl, U.S.N. Fourth edition, revised.
- No. 29. STEAM INJECTORS; THEIR THEORY**
and Use. Translated from the French by M. Leon Pochet.

- No. 30. MAGNETISM OF IRON VESSELS AND**
Terrestrial Magnetism. By Prof. Fairman Rogers.
- No. 31. THE SANITARY CONDITION OF CITY**
and Country Dwelling-houses. By George E. Waring,
Jr. Third edition, revised.
- No. 32. CABLE-MAKING FOR SUSPENSION**
Bridges. B. W. Hildenbrand, C.E.
- No. 33. MECHANICS OF VENTILATION.** By
George W. Rafter, C.E. Second edition, revised.
- No. 34. FOUNDATIONS.** By Prof. Jules
Gaudard, C.E. Translated from the French. Second
edition.
- No. 35. THE ANEROID BAROMETER; ITS**
Construction and Use. Compiled by George W.
Plympton. Eleventh edition, revised and enlarged.
- No. 36. MATTER AND MOTION.** By J. Clerk
Maxwell, M.A. Second American edition.
- *No. 37. GEOGRAPHICAL SURVEYING; ITS**
Uses, Methods, and Results. By Frank De Yeaux
Carpenter, C.E.
- No. 38. MAXIMUM STRESSES IN FRAMED**
Bridges. By Prof. William Cain, A.M., C.E. New
and revised edition.
- No. 39. A HANDBOOK OF THE ELECTRO-**
Magnetic Telegraph. By A. E. Loring. Fourth edi-
tion, revised.
- *No. 40. TRANSMISSION OF POWER BY**
Compressed Air. By Robert Zahner, M.E.
- No. 41. STRENGTH OF MATERIALS.** By
William Kent, C.E., Assoc. Editor "Engineering News."
Second edition.
- No. 42. THEORY OF STEEL - CONCRETE**
Arches, and of Vaulted Structures. By Prof. Wm.
Cain. Fifth edition, thoroughly revised.
- No. 43. WAVE AND VORTEX MOTION.** By
Dr. Thomas Craig, of Johns Hopkins University.
- No. 44. TURBINE WHEELS.** By Prof. W. P.
Trowbridge, Columbia College. Second edition. Re-
vised.
- No. 45. THERMODYNAMICS.** By Prof. C. F.
Hirshfeld. Second edition, revised and corrected.
- No. 46. ICE-MAKING MACHINES.** From the
French of M. Le Doux. Revised by Prof. J. E. Denton,
D. S. Jacobus, and A. Riesenberger. Sixth edition,
revised.

EXPLOSIVE MATERIALS

The Phenomena and Theories of Explosion

AND THE CLASSIFICATION, CONSTITUTION
AND PREPARATION OF EXPLOSIVES

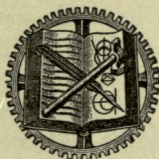
BY

COLONEL JOHN P. WISSER

COAST ARTILLERY CORPS

Military Attache to the American Embassy in Berlin

Second Edition, Revised and Enlarged

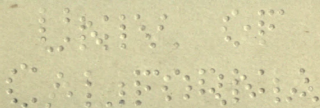


NEW YORK

D. VAN NOSTRAND COMPANY

23 MURRAY AND 27 WARREN STREETS

1907



±TP 270
W8

Copyright 1898, 1907,

BY

D. VAN NOSTRAND COMPANY.

PREFACE.

THE first edition of this number of *Van Nostrand's Science Series* having become exhausted, it became necessary, in order to keep the series complete, to issue a new edition. But in the fifteen years which have elapsed since the appearance of the first edition, many changes have taken place in the views regarding the phenomena of explosions, and many new explosives have attracted the world's attention, particularly the important class of smokeless powders. Therefore, since the theory advanced by Berthelot no longer accounts for *all* the known phenomena, it was deemed best by the publishers to have the entire number rewritten.

The present volume is the result of this decision. The subject-matter is based on the original essay of Berthelot, and such

matter has been added, as it is believed, will render the little work more generally useful.

We are indebted to Prof. J. P. Cooke of Harvard University for the first clear explanation of the action of explosive compounds, and for directing attention to the necessity for studying structural formulæ in this connection. The few pages devoted to the subject of explosives in the new work of Professor Tillman of the U. S. Military Academy, present the subject in simple language, but in a most satisfactory way, especially as regards the distinctions between the classes of explosive compounds. But the greatest authority on explosives in this country is probably Professor C. E. Munroe, formerly of the U. S. Naval Torpedo Station, now of Columbia University, Washington, D. C. Traces of his work are evident in all the later literature on the subject, and much of the interest in the field of explosives in this country was inspired by his labors. Lieutenant Walke, in charge of the Department of chemistry and explosives at

the U. S. Artillery School, has embodied the gist of Professor Munroe's lectures in the new edition of his work, which has, besides, excellent descriptions of the latest processes of manufacturing the principal explosives. The dictionary of Lieutenant-Colonel J. P. Cundill, R. A. (now in its second edition) is, of course, invaluable in the study of the latest forms of smokeless and other powders, and we were fortunate, too, in learning the views of Professor Mendeléef on explosives, through the *Proceedings U. S. Naval Institute*, *Revue d' Artillerie* and *Arms and Explosives*.

The author, therefore, desires to express his obligations to the following works, besides the original volume (No. 70) of this series.

The New Chemistry. Prof. J. P. Cooke, Jr.
D. Appleton & Co.

Descriptive General Chemistry. Prof. S. E.
Tillman, U. S. Military Academy.

Lectures on Chemistry and Explosives. Prof.
Charles E. Munroe, Naval Torpedo Station.

Lectures on Explosives. Lieut. W. Walke, U. S.
Artillery School. Wiley & Sons.

Ordnance and Gunnery. Capt. L. L. Bruff,
U. S. Military Academy. Wiley & Sons.

Dictionary of Explosives. Lieut. - Col. J. P.
Cundill, R. A. London : Eyre & Spottiswoode.

Militaer - Wochenblatt. Mittler u. Sohn, Berlin.

Proceedings U. S. Naval Institute. Annapolis,
Md.

Revue d' Artillerie. Paris, France.

Arms and Explosives. London, England.

J. P. W.

FORT MONROE, VA.,
March 8, 1898.

EXPLOSIVE MATERIALS.

An *explosive*, in the most general sense, is a substance capable of a sudden and considerable increase of volume.

This increase of volume may be the result of purely physical changes, or both physical and chemical changes.

The expansion of gases by heat, the explosive action of which is exemplified in the bursting of boilers; the expansion of gases by diminution of pressure in the surrounding medium, illustrated in the cyclone, when the low barometer area passes over a closed house; the bursting of iron shells by the freezing of water confined in them; and many similar phenomena are examples of explosive effects purely physical in character.

The explosion of an explosive mixture of gases is the simplest example of both

chemical and physical action, the gases first combining chemically, then the heat produced by this chemical action expanding the resulting gas or gases physically. The explosion of gunpowder, guncotton or nitroglycerine involves, in addition, the physical change of state from solid or liquid to gas.

Explosive materials or *Explosives*, in a restricted sense, are substances capable of a sudden and great increase of volume, due to a change of state from solid or liquid to gas, accompanied by chemical action resulting in the evolution of great heat, the latter aiding in increasing the original volume by expanding the gases produced.

Explosive materials may be divided into three classes:

- I. Compounds.
- II. Mixtures, containing nitro-compounds or organic nitrates.
- III. Mixtures, containing no nitro-compounds nor organic nitrates.

Chemical action takes place only at infinitely short distances. Now, the chemi-

cal molecules of substances are infinitely smaller than the smallest particles into which substances can be mechanically divided, and since, in the case of compounds, reaction takes place between the atoms of each molecule, we have the most favorable conditions (in this respect) possible. In mechanical mixtures of any kind, however finely divided the ingredients may be, their particles are still of appreciable size, and very large as compared with molecules. Now, in the case of explosives of the second class the reactions take place partly between the atoms of the same molecules, and partly between the atoms of different molecules, in the former the reacting atoms being at infinitely small distances apart, in the latter all except those at and near the surfaces of contact of the different particles being at considerable distances apart; hence, the conditions are less favorable than in case of plain compounds. Finally, in the case of explosives of the third class, the essential reaction takes place entirely between elements of different substances;

hence, the conditions are the least favorable.

Explosives are also classified as *high explosives* and *low explosives*, the former including those in which the chemical action is rapid and energetic, the latter those in which the action is relatively slow ; one producing a crushing or shattering effect, the other a propelling or pushing effect. Technically, the high explosives comprise the first two classes of explosive materials, the low explosives the third class, but the terms are merely relative, ordinarily, so that the chlorate group of the third class may be regarded as high when compared with the nitrate group, whereas some of the modern smokeless powders, since they are fit for use in cannon and small-arms, although containing high explosive ingredients, are themselves low explosives.

THE PHENOMENA OF EXPLOSION.

The various explosives differ greatly in force of explosion, and even in the same explosive the force is modified by the

physical condition of the explosive, the external conditions surrounding the explosive, and the method of initial inflammation.

In all cases where the chemical reactions are accurately known, the following data are required to define the action of the explosive:

1. *The chemical composition of the explosive.*
2. *The chemical composition of the products of explosion at every step (including dissociation).*
3. *The rapidity with which the action takes place, comprising both the rapidity of changes at the origin of the reactions and the rapidity of propagation of the reactions (including explosion by influence).*

In all cases where the chemical reactions are not accurately known, the following data are required to define the action of the explosive:

1. *The quantity of heat given off during the reaction.*

2. *The volume of the gases formed* (measured under normal pressure).
3. *The rapidity with which the reaction takes place*, comprising both the rapidity of changes at the origin of the reactions, and the rapidity of propagation of the reactions (including explosion by influence).

CHEMICAL COMPOSITION OF EXPLOSIVES.

The characteristic features common to all explosives are their instability and their capacity to form very rapidly a large volume of gaseous products. Their instability is due to the fact that the elements present are not combined with one another according to their greatest affinities, a condition which leads to their easy and rapid decomposition with little loss of heat, while their capacity to form rapidly a large volume of gaseous products depends on their rapid decomposition, on the fact that the elements tend to re-combine according to their greatest affinities, therefore giving off great heat, and on the fact

that the products are gaseous, and are expanded by the resultant heat.

In the case of explosive gases, or mixtures of gases, there is no change of state, but in all ordinary explosives there is a change of state from liquid or solid to gas, which still further increases the effect.

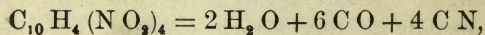
All ordinary explosives, except a few of the chlorate class of mixtures, contain nitrogen, an element of very feeble affinities, and to it their instability is largely due, but is also increased by the fact that other elements present are not combined according to their greatest affinities. In the chlorates the weak element is the chlorine, not because it is generally a weak element for it is on the contrary usually a very strong element, but because in these compounds it is united according to its weakest affinity, that is with oxygen.

The foregoing considerations are sufficient to explain the explosion of the binary nitrogen compounds.

But, all explosives, which have received

important practical application, have in addition to the element of instability, nitrogen (or chlorine in the chlorates), the oxidizable elements carbon and hydrogen (or carbon alone) and oxygen. Explosion in such cases is really a form of combustion, the reaction being very energetic and rapidly propagated. In explosive *compounds* these elements are all present *in the molecule*, but combined in a manner not according to their greatest affinities, and in order to understand the action in their explosion it is necessary to study their structural formulæ.

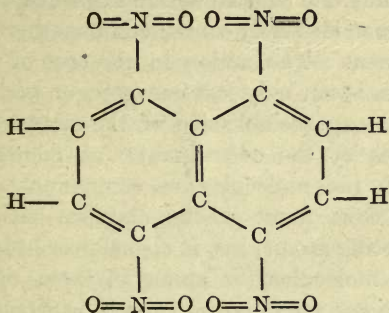
Thus, the explosion of tetra-nitro-naphthalene may be represented by the following equation:



but this reaction in itself does not explain the *production of heat*, because true simple decomposition (not complicated by further recomposition) always *absorbs heat*, and if the elements were combined, and their affinities satisfied in the original compound exactly as they are in the products then

cold would be the result of the change and not heat.

The structural formula, however, makes all this clear.



The oxygen atoms are not united directly to either hydrogen or carbon atoms; indeed, they are removed as far as possible from the hydrogen atoms (for which their affinity in this molecule is greatest), and are connected with the carbon atoms (their next greatest affinity) only through an atom of nitrogen (for which they have the least affinity). When explosion takes place the molecule is broken up, and

the oxygen atoms rush for the carbon and hydrogen atoms, their energy being made evident in the form of heat.

In mixtures the oxidizable substance is usually one constituent and the necessary oxygen is usually contained in another constituent. The action in the case of mixtures is not only less energetic on account of the appreciable size of the minute particles of the constituents (as compared with the molecules of compounds) and the consequent greater distance between reacting atoms, but is also slower because the molecules (or atoms in them) of the particles are removed from the surface of the particles in succession, the latter wearing away in successive layers as the action continues. Hence, true mixtures (those in which the principal reaction is between atoms of different molecules) are less energetic than true compounds, or than those mixtures containing nitrous or nitric derivatives, (in which the principal reaction is between atoms of the same molecule).

The practically useful explosives are in

the liquid or solid state, and this for two reasons, *first*, because they are easier to transport and handle, *secondly*, because the change of state to gas implies an increase in the increase of volume. In the case of true mixtures there is another advantage in the fact that a large quantity of oxygen, available for the oxidation of the carbon or hydrogen, is concentrated in a very small volume (in the form of nitrates, chlorates, etc.), resulting in greatly increased chemical activity when oxidation once begins, and a higher temperature is thus produced because the action takes place in a small space, and the heat evolved is better utilized in raising the temperature of the products; moreover, the oxygen atoms are probably separated from these compounds in the nascent state, that is, as separate atoms (O), with high combining power, and not as molecules ($O=O$), in which the affinity of the atoms is satisfied (in a low degree) by other atoms of the same kind, as it exists in gaseous oxygen or atmospheric air.

THE ORIGIN OF THE REACTIONS.

Every chemical compound is determined by the kind, the number, and the arrangement of the atoms in its molecule. The molecules of all substances are in constant motion. Anything that increases the amplitude of the vibrations beyond a certain limit, breaks up the molecule. Thus, heat (a form of molecular motion) is one of the commonest agents used to decompose compounds; light (another form of molecular motion) decomposes compounds in photography and in vegetable life; and finally, electricity (still another form of molecular motion) causes chemical decomposition in electrolysis.

The origin of the chemical transformation in explosion is always some force due to matter in motion, either the motion of the matter in mass, such as a shock, pressure or friction, or the motion of the molecules of bodies, such as heat, synchronous vibration (sound waves,) or vortex-ring motion. This motion, if motion in mass, is communicated to the molecules

of the explosive, is transformed into heat, and appears at the initial point as that effect of heat called temperature, every explosive having its particular temperature of explosion, which, however, varies within certain limits, depending on the rate at which the heat is communicated, substances being able to exist at temperatures above their temperature of decomposition, but for a time which decreases as the temperature rises.

If the motion be that of vibrations synchronous with those which would result from the explosion of the substance considered, the latter being in a state of high chemical tension, it is communicated through space, without appreciable change of temperature at any particular point, to the molecules of the explosive, and either produces its explosion directly, or makes it more sensitive to the effect of shock, thus causing its explosion indirectly.

If vortex motion is set up by explosion at one point, due to the fact that the surfaces surrounding the explosion gases are more curved at some points than at

others, producing the greater strain at the points of greater curvature, then at short distances from the center of disturbance greater effects are produced in some directions than in others, and these effects may again lead to explosion; at considerable distances the effects tend to become uniform in all directions.

The last two actions explain sympathetic explosions, or explosions by influence.

The physical condition of an explosive has a great influence on the explosive reaction: thus, frozen nitro-glycerine can be fired only with great difficulty, and wet guncotton requires a primer of dry guncotton.

THE RAPIDITY OF THE REACTIONS.

The rapidity of the chemical reaction in explosion varies greatly in different explosives, and even in the same explosive is much affected by various circumstances.

The rapidity of the reaction increases with the temperature according to a very

rapid law; it also increases with the pressure in the case of gaseous explosives; and finally, it depends upon the relative proportions of the components.

The presence of an inert body since it absorbs heat and consequently lowers the temperature, without exerting any influence to hasten the reaction, retards the actions. In this way the character of an explosive may be modified or entirely changed.

When the speed of the reactions is not great, a portion of the heat is dissipated, and the rise of temperature soon ceases. This limit is that at which the loss of heat by radiation, conduction, etc. is equal to the gain due to the internal reactions. In this case the reaction takes place with a nearly constant rapidity, and does not become explosive, but produces what is called *deflagration*.

Explosions resulting from simple spontaneous decomposition are explained in the same way. A small mass of such a substance would merely decompose, but a large mass, since the heat produced inter-

nally might increase considerably while the loss of heat externally might not change materially, could have its temperature raised so as to produce explosion instead of simple decomposition.

THE PROPAGATION OF THE REACTIONS.

The explosive reactions in a homogeneous gaseous mixture, surrounded by conditions of pressure and temperature identical in all its parts, should, apparently develop instantaneously in all parts at once. But, as a matter of fact a certain amount of time is consumed in the process, and this time varies in different bodies.

Now, in the ordinary case of explosives, the different parts of which are exposed to different conditions, such as those which arise from being ignited at one point or from a local shock, in order that the transformation may be propagated with explosive effect, it is necessary that the same physical conditions of temperature, of pressure, etc. which prevail at the initial point, should successively be pro-

duced and propagated, molecule by molecule, through all portions of the mass.

The rapidity of combustion of explosives depends to a great extent on the pressure of the air or the surrounding gases. Thus the velocity of the combustion of gunpowder in the open air is about 10 to 13 mm. a second, whereas in the bore of a gun it is about 230 mm. a second (Piobert). The rapidity of progressive combustion of uncompressed guncotton is about eight times that of gunpowder (Piobert), therefore about 100 mm. a second, while that of compressed and detonated guncotton is about 5000 m. a second (Dr. Rudolf Blochman).

In granulated mixtures, especially low explosives, the size of the grain has a great effect on the velocity with which the reactions are propagated.

Finally, by varying the process used for originating the reactions any effect from quiet decomposition without flame to perfect detonation may be produced, even in high explosives.

Generally, two kinds of explosion are distinguished :

Explosions of the first order or detonation.

Explosions of the second order, or ordinary explosion.

All explosions are brought about by heat, synchronous vibrations or vortex motion. Heat may be applied directly as heat, or indirectly as a shock, which is converted into heat. The order of explosion if due to shock, depends on the intensity of the original shock, therefore, *detonators* consisting of small quantities of some violent explosive, are used to produce explosions of the first order.

In case of detonation by shock the pressures resulting from the shock are too rapid to become uniformly dispersed throughout the entire mass, and the energy is transformed into heat in the first layers of the explosive; these layers are detonated and the resulting gases produce a new shock on the next layer, raising its temperature and detonating it in the same way, and so on, the effect being thus propagated with great rapidity by the alternate

conversion of energy into heat and heat into energy. To produce detonation the initial velocity of decomposition must rise above a certain minimum value, and there is therefore a *critical velocity* of initial decomposition which determines the kind of reaction that ultimately takes place; and there is a minimum temperature which some part of the explosive must reach in order to have detonation by heat or shock.

In detonation by influence the explosive either takes up the vibrations of the detonator throughout its mass and thus detonates itself, or the vortex motion caused by differences in the surfaces surrounding the initial explosion, since its effects are greater in certain directions than in others, will detonate the explosive if it be in one of these paths of greater effect.

Ordinary explosion results as follows: the portion of the substance first heated explodes, the gases by expansion are cooled, but still heat a small portion of the explosive to the temperature of explosion; this then explodes, cooling again takes place, and so on.

The sensitiveness of an explosive is dependent on the individual structure of the explosive, on the conditions of heating, and on the method of propagation of the reactions; it is greatest for the same substance at temperatures nearest to that at which the substance begins to decompose spontaneously; it depends, in different substances, on the cohesion of the substance which governs the transformation of the shock into heat, on the temperature of decomposition, and on the quantity of heat set free by the decomposition.

Thus, mercury fulminate detonates at a higher temperature than silver oxalate and at a lower one than nitrogen sulphide, yet it is much more sensitive to shock or friction than either of these substances. Celluloid, which does not detonate at ordinary temperatures, acquires that property at a temperature approaching that at which it decomposes. The temperature of decomposition is lower for potassium chlorate than for the nitrate, and the former is the more sensitive.

THE PRODUCTS OF EXPLOSION.

Equations representing explosions (like all other chemical reactions) are not deductive, but are the result of observation and experiment.

Nevertheless there are certain general principles which enable us to write out the equation that represents the principal reaction in the explosion, when we know the exact chemical composition of the components.

In the explosion of compounds containing carbon, hydrogen, oxygen and nitrogen, we know that the hydrogen first takes all the oxygen it requires to oxidize to water vapor. If there be any excess of hydrogen it will combine with some of the carbon and form marsh gas; if there be an excess of oxygen (above what is required by the hydrogen) it will combine with carbon and form carbon dioxide, if there be enough oxygen, or carbon monoxide, if there be no more oxygen than is required to convert the carbon to this oxide, or both these oxides, if there be an

intermediate quantity of oxygen; if there be an excess of oxygen above that required by the hydrogen, but below that required to convert all the carbon into carbon monoxide, free carbon would be left, but this combines with nitrogen to form cyanogen, or with hydrogen to form marsh gas; if there be an excess of oxygen above that required to oxydise all the hydrogen to water vapor and all the carbon to carbon dioxide, it is given off in the free state; nitrogen is generally given off in the free state, but if there be an excess of carbon it may appear in part as cyanogen.

Of course, some of the gaseous products undergo dissociation at the temperatures produced by the explosions, but the fact that a material slowly decomposed at a given temperature is able to exist for a short time at much higher temperatures, prevents much dissociation from taking place. The abruptness of cooling immediately after explosion preserves these compounds from destruction, because it brings them to temperatures at which they are stable.

These principles are the basis of the preparation of certain of the explosive mixtures. Compounds which have a deficiency of oxygen are made more energetic in their explosive action by mixing them with some oxidizing agent; and compounds with an excess of oxygen can be advantageously mixed with those having a deficiency, or with some oxidizable substance.

The total quantity of heat given out in any chemical reaction is fixed, no matter what its rate, but the temperature to which the products are raised depends, among other things, on the specific heat of these products, hence, explosives whose products have a low specific heat have an advantage over those with a high one; and since dissociation tends to lower the temperature, the more permanent the gases in the products the better.

THE FORCE OF EXPLOSION.

The force of explosion may be measured

either by the *pressure* of the gases given off, or by the *work* done.

The pressure of the gases depends upon their nature, their volume and their temperature.

The work done depends upon the quantity of heat given off. The *maximum* work which an explosive is capable of doing, or its *potential energy*, is determined by multiplying the number of units of heat given off by the mechanical equivalent of a unit of heat; but it must be remembered that it is a limit which is never reached in practice, because there is always loss of heat as such, by conduction, radiation, etc., moreover, part of the work done is not useful work and is therefore lost. Finally, much of the heat remains stored up in the gases that escape.

To fully define the force of an explosion, however, after we consider both the pressures of the gases evolved and the work which the heat given off is capable of doing, the following data are necessary;

1. The chemical composition of the explosive.

2. The chemical composition of the products of explosion at every step (including dissociation).
3. The quantity of heat given off during the reaction.
4. The volume of the gases formed (measured under normal pressure).
5. The rapidity with which the reaction takes place, comprising both the rapidity of the changes at the origin of the reactions, and the rapidity of propagation of the reactions (including explosion by influence).

Of course, if the chemical reactions are positively known the third and fourth may be deduced from the first and second.

The various kinds of explosives, based on the force of their explosion, are used for different purposes.

Strong and very rapid explosives.—Strong and very rapid explosives are used when it is desired to obtain principally breaking effects. In their case the elasticity of the mass acted upon has not time to come into play and the material is broken into small fragments. In their employment in

mining it is not necessary to tamp much because the pressure is communicated to the solid rock before the gases formed have time to drive away the compressed air.

Fulminate of mercury and the stronger dynamites are the types of the strong and very rapid explosives.

Strong and less rapid explosives.—If the decomposition of strong and very rapid explosives be retarded a little, the potential energy still remaining considerable, there will be a tendency to produce a tearing or shearing in the lines of least resistance, and when the tenacity is not great the result is dislocation without projection. These explosives are used in quarrying large blocks of rocks of great resistance.

The weaker dynamites are the types of this class, but the stronger can also be used in case the block is outlined by a furrow with a central drill-hole, or by making the effect of successive small explosions in the same chamber cumulative.

Strong and slow explosives.—Strong and slow explosives are used when it is de-

sired to break the material into as large pieces as possible, as in mining coal, or merely into a comparatively small number of pieces, as in the bursting of shell. The gradual increase of pressure is of advantage for some purposes, as in the displacement of earth.

Ordinary gunpowder is the type of the strong and slow powders, but the modern mixtures containing high explosives are so varied in their qualities that all shades of effect can now be produced by them.

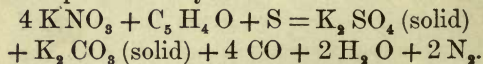
The order of the explosives according to their respective strengths, or forces of explosion, varies considerably according to the instrument used in measuring them, or the method employed, so that any order must be regarded in a general sense, and not as in any way absolutely accurate.

The following table condensed from a more complete one in Lieutenant Walke's *Lectures on Explosives*, gives the order of the principal explosives according to the force of explosion, as determined by the Quinan pressure-gauge:

Explosive gelatine	-	-	-	106.17
Helehoffite	-	-	-	106.17
Nitroglycerine	-	-	-	100.00
Guncotton (U.S.N. Torpedo Station)				83.12
Dynamite, No. 1	-	-	-	81.31
Emmensite	-	-	-	77.86
Tonite	-	-	-	68.24
Bellite	-	-	-	65.70
Atlas Powder	-	-	-	64.43
Rackarock	-	-	-	61.71
Mélinite	-	-	-	50.82
Mercury fulminate	-	-	-	49.91
Mortar Powder (Dupont)	-	-	-	28.13

Professor Mendeléef proposes, as the most reliable way of comparing the ballistic efficiencies of powders, the simple consideration of the volumes of evolved gases, without regard to conditions of temperature.

Thus, if the explosion of brown powder be represented by:



$$\text{Mol. wt.} = 4 \times 101 + 80 + 32 = 516.$$

$$\begin{aligned} \text{Vols. of gases} &= 4 \times 2 + 2 \times 2 + 2 \\ &\times 2 = 16. \end{aligned}$$

We have, $516 : 16 :: 1000 : V_{1000} = 31.0$. That is, a thousand parts by weight of the explosive furnish 31 volumes of gas (measured at a fixed temperature and pressure).

For pyrocollodion, $V_{1000} = 81.5$. Hence, the relative energies of brown powder and pyrocollodion for equal weights are as $81.5 : 31.0$, which is very nearly what actual experiments show, viz.: $2.6 : 1$.

Admitting the effect of temperature, he holds that our methods of determining the temperatures developed by explosives are unreliable, and our assumptions in regard to the specific heats of gases at high temperatures may be wrong, hence, the volumes of gases are our only safe means of comparison.

THE SPRENGEL CLASS OF EXPLOSIVES.

The Sprengel safety mixtures are based on the principle of keeping separate, for safety in handling, transportation and storage, the essential constituents of an explosive mixture (an oxidizable substance

and an oxidizing agent), and mixing them only when required for use.

The separate constituents are, of course, not explosive, and can be manipulated with safety. The mixing of those which have received practical approval can also be effected with safety, but it is difficult to secure uniformity in the resulting explosive without special mixing apparatus worked by skilled workmen.

These explosives are all powerful, and most of them are very stable, requiring strong detonators to explode them perfectly. They possess another advantage in that the power may be varied considerably by simply varying the proportions of the ingredients in mixing before use. The principal disadvantages are that they require workmen of more than ordinary intelligence, that in mine galleries and other confined localities it is inconvenient and dangerous to mix those containing essentially nitric acid or carbon bisulphide, and finally, that it is necessary to protect the copper capsule containing the detonator from the action of the nitric acid in

those which contain this acid as an essential ingredient.

The principle explosives of this class are :

Rack-a-Rock,
Hellhoffite,
Oxonite,
Panclastite, and
Romite.

SMOKELESS POWDERS.

The principle involved in the preparation of smokeless powder is the production of an explosive which shall have in its products of explosion no gases readily condensible into liquids or solids, and at the same time give moderate pressures.

The demand for the smokeless powders was created by the modern magazine small-arms and the rapid-fire and machine guns, because the accumulation of smoke with the old powders soon put a limit to the use of these powerful engines. But these new powders are rapidly finding application not only in military arms but also in sport-

ing rifles and elsewhere, and are fast superseding the old ones.

The only class of smokeless powders that has proven practically useful and reliable is that derived from guncotton or its modifications (with or without nitro-glycerine).

In stability and ballistic properties these powders are generally superior to the old powders. They are more difficult to ignite than black powder and require stronger caps; they are unaffected by water or air; they are not sensitive to shock and leave no residue when burned; and they give high velocities with comparatively low pressures, and great uniformity of action.

The force of these powders is explained by the fact that the potential energy is high, since the quantity of heat evolved is large, and that the total volume of gas given off is very great. The low pressures, on the other hand, are explained by the fact that the rapidity of reaction in these mixtures has been greatly decreased below that of the high explosives entering into their composition, by the admixed de-

terrents, and by the physical form given them in practice, so that the gases are given off comparatively slowly; moreover, the gases can expand into the *entire* space behind the projectile, whereas in gunpowder over *half* the space is occupied at the moment of explosion by solid gunpowder, and less than half is therefore available for the gases to expand into; while the high velocities given to the projectile, with such low pressures (which, as measured, are not the average pressures while the projectile is in the bore, but the *maximum* pressures reached) are explained by the fact that, although the initial pressure is less, the total force exerted on the projectile while it is in the bore, due to the great volume of gas and the high potential energy, is greater; moreover, in these smokeless powders none of the force is wasted in throwing out the unconsumed powder, as it is in the case of black, or even brown, gunpowder. Finally, it is probable that dissociation (the effect of which is explained under *Brown Powder*) comes into play. The low pressures also

account for the fact that these powders, although they contain high explosive constituents, do not detonate.

They are, in reality, strong and slow powders, but in a special sense: strong, as compared with gunpowder (not so strong as guncotton or dynamite), and slow, as compared with the high explosives (but more rapid *in reality* than gunpowder), with the *effect* of being less rapid even than gunpowder, on account of the *entire* space behind the projectile being available for the gases to expand into.

In an exhaustive study of the general subject of smokeless powders, the Russian chemist, Professor Mendeléef, arrived at the following conclusions in regard to the kind of substances that promise to be used in future in the manufacture of these powders.

The conditions to be fulfilled by smokeless powders are :

1. That they shall leave no solid residue after combustion, and that their gases exercise no injurious effect upon the metal of the gun.

2. That they undergo no change upon keeping for long periods of time, and contain no volatile ingredients.

3. That they may be readily prepared in quantities sufficiently abundant for practical needs.

The first condition limits the substances suitable for conversion into powder, to compounds of hydrogen and nitrogen with oxygen and carbon. But in any powder the energy is derived from the conversion of the mass into gases, the transformation being accompanied by great heat. The greatest volume of gas (measured at a fixed temperature and pressure) would be obtainable from H_{2n} in the solid or liquid form (provided such a substance existed), for we should then have:

$$H_{2n} = n H_2, \text{ or } V_{1000} = 1000,$$

but no such substance is known, or expected.

The binary compounds, while giving larger volumes of gas ($V_{1000} = 133.3, 93.0$, etc.) than any others, do not fulfill the third condition, but even if they did, such

compounds do not decompose gradually enough to be used in guns. The necessary progressive combustion can take place only in explosives containing carbon and hydrogen, which are consumed by the oxygen that is held in close proximity to them, but which is not directly combined with them.

I.—COMPOUNDS.

Explosive *compounds* may be divided into five groups :

1. Nitrides.
2. Azo-Compounds.
3. Fulminates.
4. Nitro-Compounds.
5. Organic Nitrates.

There are a few compounds not included in this classification, but they are of little importance practically, and add nothing to our understanding of the theory of explosives.

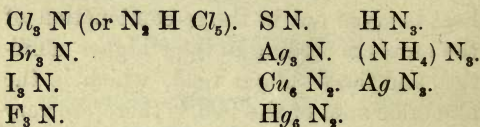
The explosive character of all these compounds is due to three great causes: *first*, they are comparatively unstable com-

pounds, all of them containing nitrogen, the most indifferent of all the elements so far as chemical affinity is concerned, and therefore their molecules are readily broken up; *secondly*, the atoms in the molecule are not combined according to their greatest affinities, hence, little heat is absorbed in decomposing the molecules, while great heat is given out in the re-combination of the atoms according to their higher affinities, and the resultant heat, which is the algebraic sum of the two, is therefore very great; and *thirdly*, the products are all gases at the temperature produced by the explosion, and most of them permanent gases. Hence, all the conditions for explosive action are present and in a high degree, viz.: *change of state* from solid or liquid to gas, *rapid chemical change*, evolution of *great heat*, and the production of a *large volume of gas*; in other words, a small volume of the explosive can suddenly produce a very large volume of gas.

I.—NITRIDES.

This group comprises the simplest of

the explosive compounds. Some may be regarded as formed theoretically from ammonia, NH_3 , by replacing all (or part) of the hydrogen by another (metallic) element, others from hydrazoic acid, HN_3 , by replacing the hydrogen by a metallic element, and are therefore all nitrides (or hydro-nitrides):



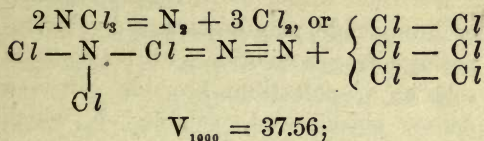
Nitrogen Chloride.—Nitrogen chloride, or Chloramide, is formed by passing chlorine gas into a warm solution of sal-ammoniac. It is a heavy oily liquid. When heated to $93^\circ C$. it explodes violently, and its explosion is also caused by contact of substances which have an affinity for chlorine, such as phosphorus, arsenic, oils, turpentine and alkalies.

Its exact chemical symbol has not been determined, but it is usually regarded as $NC l_3$. Its structural formula will there-

fore be $\text{Cl} - \text{N} - \text{Cl}$ and its explosion may

$$\begin{array}{c} | \\ \text{Cl} \end{array}$$

be represented by the equation



the evolution of heat in this case is explained by the fact that the heat required to decompose the explosive molecule (which involves only the overcoming the affinity of nitrogen for chlorine, as seen in the structural formula), is very small, while that evolved in the union of the nitrogen atoms to form the nitrogen molecule, and of the chlorine atoms to form the chlorine molecule, is very great, the resultant effect being the evolution of a large quantity of heat.

Nitrogen Iodide.—Nitrogen iodide, or iodoamide, NI_3 , may be made by gently triturating in a porcelain mortar finely divided iodine with a large excess of

concentrated ammonia water at 0°C . It is a brownish-black powder, which may be exploded when dry by the touch of a feather, and under water by friction.

Nitrogen Bromide.—Nitrogen bromide, or Bromamide, may be formed by decomposing nitrogen chloride with an aqueous solution of potassium bromide. It is a dense, blackish-red, volatile oil, which may be exploded violently by contact with phosphorus or arsenic, which have a great affinity for bromine.

Nitrogen Fluoride.—Nitrogen fluoride, or Fluoramide, may be formed by passing an electric current through a concentrated solution of ammonium fluoride. It is an oily liquid, which may be exploded by contact with glass, silica, or organic matter (due to the affinity of fluorine for silicon or hydrogen).

Nitrogen Sulphide.—Nitrogen sulphide, or Sulphur nitride, N S , may be prepared by passing dry ammonia gas through a solution of sulphur dichloride in ten or twelve times its volume of carbon bisulphide, filtering off the yellow liquid, allowing it to

crystallize by spontaneous evaporation, and dissolving out the admixed sulphur by carbon bisulphide. It is a golden yellow, crystalline solid, which can be exploded by percussion.

Silver Amine.—Silver amine, or Silver nitride, $Ag_3 N$, may be prepared by acting on silver oxide with ammonia. It is a black powder, which is exploded by the slightest shock.

Copper Amine.—Copper amine, $Cu_6 N_2$, is formed by passing dry ammonia gas over finely powdered cupric oxide heated to $250^\circ C$. It is a dark green powder, exploding at $310^\circ C$.

Mercury Amine.—Mercury amine, $Hg_6 N_2$, may be prepared by passing dry ammonia gas over dry mercuric oxide, and then heating the resulting mass cautiously at a temperature not exceeding $150^\circ C$. It explodes by heat or percussion.

Nitrohydric Acid.—Nitrohydric acid, or hydrazoic acid, $N_3 H$, is very explosive itself and forms highly explosive salts. It furnishes a remarkably great volume of

gas: $2 \text{N}_3 \text{H} = \text{H}_2 + 3 \text{N}_2$, so that $V_{1000} = 93.0$.

Ammonium Hydrazoate.—Ammonium hydrazoate, $\text{N}_3 (\text{N H}_4)$, is the ammonium salt of hydrazoic acid, and is also explosive: $\text{N}_3 (\text{N H}_4) = 2 \text{H}_2 + 2 \text{N}_2$, giving $V_{1000} = 133.3$.

Silver Hydrazoate.—Silver Hydrazoate,

$\text{N}_3 \text{Ag}$, or $\text{Ag} - \text{N} \begin{array}{c} \text{N} \\ \diagup \text{=} \text{N} \\ | \end{array}$, is the silver salt, and has been proposed as a substitute for mercury fulminate.

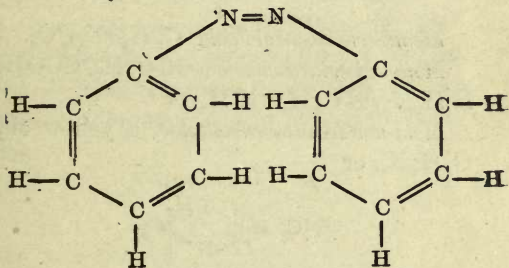
None of these compounds have as yet received any important practical application, although silver amine is supposed to have been the initial detonating agent in the bomb that killed the Czar, and nitrogen sulphide could be used as a substitute for mercury fulminate; but they are interesting in connection with the theory of explosives.

2.—AZO-COMPOUNDS.

The azo-compounds are derived theoretically from the benzene series by substitu-

tion of 2 atoms of nitrogen for two atoms of hydrogen. Practically, they are prepared by the action of reducing agents on the nitro-derivatives of the benzene series, or by the oxidation of aniline (prepared from nitro-benzene).

Thus, azo-benzene, $C_{12}H_{10}N_2$, is formed by the action of sodium-amalgam on nitro-benzene. Its structural formula is:

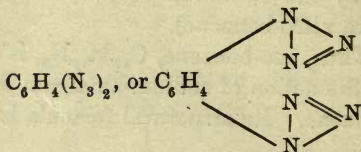


P. Griess, the great German investigator of the azo-compounds, isolated a number of explosive salts of this class, most of which are crystalline. They are interesting in the theoretical study of explosive compounds, and may find some practical

application in the future.—(*Berichte Deutsche Chem. Gesell.*)

The more important are :

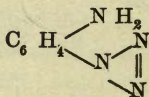
Paraditriazobenzene,



Metaditriazobenzoic acid, $\text{C}_7\text{H}_5(\text{N}_3)_2\text{O}_2$.

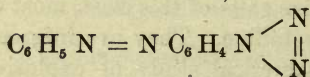
Metamidotriazobenzoic acid, $\text{C}_6\text{H}_3, \text{COOH}, \text{NH}_2, \text{N}, \text{NC}_6\text{H}_2, (\text{NH}_2)_2$.

Meta-amidodiazobenzolimide, a yellow oil, $\text{C}_6\text{H}_6\text{N}_4$, or



Para-amidodiazobenzoic acid, $\text{C}_7\text{H}_5\text{N}_3\text{O}_2$.

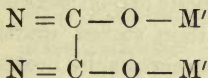
Triazo-Azobenzene,



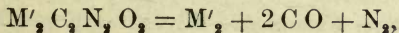
3.—FULMINATES.

The fulminates are intermediate in composition between the binary nitrogen compounds and the nitrous derivatives of the benzenegroup. They contain some oxygen, but only enough to convert the carbon into carbon monoxide. They are generally regarded as salts of fulminic acid, $C_2 N_2 O_2 H_2$.

Their explosive action is explained by the fact that in the molecule the atoms of the elements are united in a manner which is not according to their highest affinities, and in the resultant gases they *are* so united. The structural formula is probably this:



in which part of the affinity of carbon is satisfied by that of other carbon, and another part by that of nitrogen, only one-fourth of its maximum affinity being satisfied by oxygen, whereas in the result,



one-half the maximum affinity of carbon is satisfied by oxygen.

Mercury Fulminate.—Mercury fulminate, $\text{Hg C}_2\text{N}_2\text{O}_2$, is manufactured by dissolving in a carboy one part of mercury in one part of nitric acid (sp. gr. 1.4.), the liquid, containing nitrous acid and solution of mercuric nitrate being then poured into another carboy containing ten parts of alcohol (sp. gr. 0.83.), connected through a series of Wolff's bottles placed in a trough of water, with a condensing tower. The condensed vapors are used again instead of pure alcohol.

The fulminate is washed and dried till it contains about fifteen per cent. of moisture, and is then stored under water, or packed in papier maché boxes containing about 8 grammes each.

It is a white or grayish crystalline substance, which explodes violently when struck, or when heated to 195°C . Its principal practical application is in the manufacture of cap composition and detonators.

Silver Fulminate.—Silver Fulminate, Ag_2

$C_2N_2O_2$, may be made by a process similar to that for making the mercury salt. It explodes much more violently than the latter, and when dry the slightest touch will set it off. It is used in minute quantities in detonating toys.

The other fulminates have received no practical application, although they are all explosive. The following are known to chemistry :

Gold Fulminate.

Platinum Fulminate.

Zinc Fulminate.

Copper Fulminate.

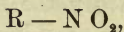
Silver-Ammonium Fulminate.

Silver-Potassium Fulminate.

4.—NITRO-COMPOUNDS.

The most important of the explosive compounds are formed by the action of nitric acid on organic substances containing carbon and hydrogen, or carbon, hydrogen and oxygen, and belong to the fourth and fifth groups.

The nitro-compounds or nitro-substitution compounds, may be represented by the general symbol



in which R is an organic radical; and they are derived from hydrocarbon compounds, or compounds of carbon, hydrogen and oxygen, by the substitution of the acid radical, $N O_2$, for the hydrogen of the organic compound, the $N O_2$ replacing, not the hydrogen of hydroxyl as required in forming oxysalts, but the hydrogen connected directly to carbon atoms, that could in a similar way be replaced by chlorine, bromine, etc. Again, if we regard the result as produced by substitution in the acid symbol, then the organic radical replaces, not the hydrogen of the acid, as in true oxysalts, but the hydroxyl. Consequently, these compounds are not salts, but true substitution products.

They are generally more stable compounds and less energetic in their action than the organic nitrates, facts which may be explained by the position of the nitryl

molecule, N O_2 , determining as it does the heat of formation (which is a measure of the stability) and the distance the atoms have to travel in recombining in explosion (a measure of the intensity of action in explosion). One of the greatest affinities nitrogen shows is for carbon, as exemplified in cyanogen, and in the molecules of the compounds included in this group (since the nitryl molecule is united *directly* to a carbon atom) this strongest affinity is partially satisfied, a fact which assists in accounting for the comparative stability of these substances.

A.

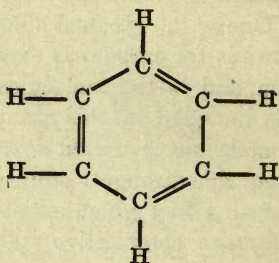
Derivatives of the Benzene (or Aromatic) Series.

The compounds in this section are formed by the action of nitric acid on the benzene series of hydrocarbons (or on derivatives of that series), resulting in the replacement of one or more hydrogen atoms by molecules of the radical nitryl, N O_2 .

The benzene series comprises the hydrocarbons of the general symbol $\text{C}_n \text{H}_{2n-6}$ in which n is at least 6. The lowest mem-

ber of the series is $C_6 H_6$, from which the others are derived by replacing the hydrogen atoms by CH_2 .

The structural formula for benzene is:



and if one of the hydrogen atoms be replaced by CH_3 , we have toluene, $C_7 H_8$; but when more than one atom of hydrogen is replaced, the product, although its chemical symbol remains the same, differs according to the position of the hydrogen atoms replaced, two adjacent ones forming the *ortho* compounds, two alternate ones the *meta* compounds, and two opposite ones the *para* compounds; such compounds, having the same chemical formula but different structural formulas are called isomeric

compounds. The position of the atom or atoms replaced affects the stability of the compound produced, the symmetrical being the more stable. This principle applies in a number of organic compounds.

This section of explosive compounds may be divided into two sub-sections:

Derivates of Benzene.

Derivates of Toluene.

a. Derivatives of Benzene.

The members of this sub-section are:

The Nitrobenzenes.

The Picrates.

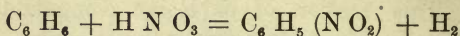
The Nitrobenzenes.

The nitrobenzenes are obtained by the nitration of benzene, C_6H_6 . Three degrees of nitration have thus far been effected, resulting in the replacement of one, two or three atoms of hydrogen by a corresponding number of nitryl molecules.

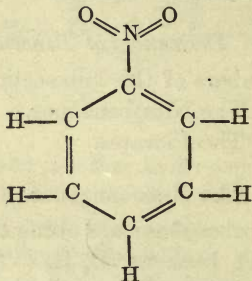
Mono-nitrobenzene. — Mono-nitrobenzene, $C_6H_5, N O_2$, is prepared by gradually adding 1 part of pure benzene to a mixture of 1.2 parts nitric acid (sp. gr. 1.4) and 1.8

parts sulphuric acid (sp. gr. 1.84), cooling by means of a current of water; the acids are then removed by means of a siphon, and the product is washed.

The reaction is thus represented :



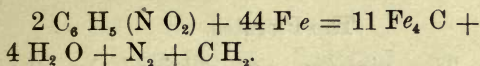
and the structural formula of the compound is :



Mono-nitrobenzene is a colorless or reddish-orange oily liquid, capable of dissolving nitrocellulose in the cold. If thrown upon an iron plate at a red heat it detonates, but under ordinary circumstances it is not an explosive.

The formula shows that there is not

enough oxygen present in the molecule to oxidize even the hydrogen, and there is a large excess of carbon, hence there cannot be explosion. On the red hot iron plate, on the contrary, this excess of carbon is taken up, forming iron carbide on the surface and liberating gases :



It is used as an ingredient of explosive mixtures, however, either as an essential constituent or as a *deterrent*, to retard or prevent explosion.

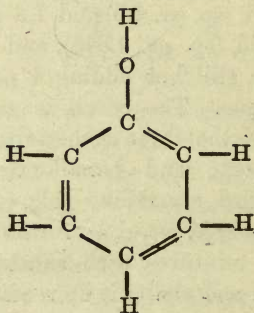
Di-nitrobenzene.—Di-nitrobenzene, $\text{C}_6 \text{H}_4 (\text{N O}_2)_2$, is prepared by mixing 0.8 parts nitric acid (sp. pr. 1.5) and 1.2 parts sulphuric acid (sp. gr. 1.845), and while the mixture is still hot adding 1 part mononitrobenzene. The result is generally a mixture of the three isomeric compounds, ortho-, meta-, and para-di-nitrobenzene. It is a hard, crystalline yellow solid, not in itself explosive, but forming strong explosive mixtures with substances rich in oxygen and giving it up readily.

Tri-nitrobenzene. — Tri-nitrobenzene, $C_6H_3(NO_2)_3$, may be prepared by treating meta-di-nitrobenzene with a mixture of concentrated nitric and Nordhausen sulphuric acids. It has been proposed as a substitute for picric acid in explosive mixtures.

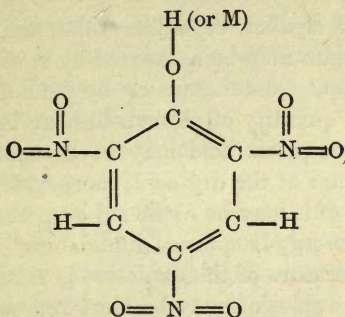
The Picrates.

The picrates are obtained by the nitration of carboic acid, or phenol, C_6H_5O , which is a derivative of benzene (one of the hydrogen atoms in the latter being replaced by hydroxyl).

The structural formula of carboic acid is:

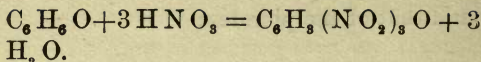


and that of the picrates:



The nitryl (N O_2) molecules are attached directly to the carbon atoms, as in the other true *nitro-compounds*.

Picric Acid.—Picric acid, or tri-nitro-phenol, $\text{C}_6 \text{H}_3 (\text{N O}_2)_3 \text{O}$, is manufactured by melting carbolic acid, mixing with strong nitric acid, diluting with water, and cooling; the picric acid crystallizes out and is purified. The reactions are somewhat complicated, but the nitric acid has its usual action in such cases, viz.: the substitution of 3 molecules of N O_2 for 3 atoms of hydrogen:



It is a yellow crystalline solid, and in the dry state may be detonated by means of a fulminate detonator, or by detonating a small quantity of picric acid near it, while the wet picric acid may be detonated by a primer of the dry acid; moreover, a thin layer of it may be exploded by percussion, the energy required diminishing as the temperature of the explosive is raised.

Its explosion may be thus represented:
 $4\text{C}_6\text{H}_3(\text{NO}_2)_3\text{O} = 6\text{H}_2\text{O} + 22\text{CO} + 5\text{N}_2 + 2\text{CN}.$

The supply of oxygen is sufficient only for the partial oxidation of the carbon, hence the use of this substance in explosive mixtures with oxidizing agents.

The explosion is explained by the presence of nitrogen, rendering the compound unstable, the fact that the elements are combined in the molecule not according to their greatest affinities, whereas in the products they are so combined, resulting in the production of great heat, and finally the change of state from solid to gas.

Potassium Picrate.—Potassium picrate, $C_6H_2K(NO_2)_3O$, is made by mixing warm potassium carbonate with a boiling solution of picric acid in water. It is a yellow, crystalline solid, which explodes by percussion or heat.

It is used in explosive mixtures with oxidizing agents.

Ammonium Picrate.—Ammonium picrate, $C_6H_2NH_4(NO_2)_3O$, is made by saturating warm picric acid with concentrated ammonia water, or by treating picric acid with ammonium carbonate. It is an orange, or citron-yellow, crystalline solid, which explodes when heated to $310^\circ C$, but is almost insensitive to blows or friction.

It is used in explosive mixtures with oxidizing agents.

b. Derivatives of Toluene.

Toluene, C_7H_8 , is the second member of the benzene series, and furnishes a series of nitro-compounds similar to those obtained from benzene.

Mono-nitrotoluene.—Mono-nitrotoluene, $C_6H_4(NO_2)CH_3$, is formed when toluene

is acted upon by a mixture of nitric and sulphuric acids, the ortho-nitrotoluene being commonly present when the mixture is heated for some time.

Di-nitrotoluene.—Di-nitrotoluene, $C_6H_5(NO_2)_2$, is prepared by treating toluene with a mixture of the strongest nitric and sulphuric acids. It is a colorless, crystalline solid, not itself explosive, but used in explosive mixtures.

Tri-nitrotoluene.— α -Tri-nitrotoluene, $C_6H_2(NO_2)_3$, (1: 2: 4: 6), is one of the products of the continued boiling of toluene in a mixture of nitric and sulphuric acids.

Tri-nitrocresol.—Cresol, C_7H_8O , is derived theoretically from toluene, by replacing one of the hydrogen atoms in the molecule by hydroxyl, just as carbolic acid is derived from benzene. Tri-nitrocresol, or *Cresilite*, $C_7H_5(NO_2)_3O$, is prepared by treating cresol with strong nitric acid.

It is a yellow crystalline solid, not explosive itself, but used in explosive mixtures.

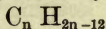
Ecrasite.—Ecrasite, $C_7H_4NH_4(NO_2)_3$,

O, is made by neutralizing a boiling-hot saturated solution of tri-nitrocresol by means of ammonium hydrate. It is a greasy yellow solid, unaffected by moisture, heat, cold or concussion, which explodes violently under the action of a fulminate detonator. It is used in Austria for charging shells, has been much experimented with, and has attracted considerable attention quite recently. The shells charged with this explosive are designed more particularly for the attack of fortifications.

B.

Derivatives of the Naphthalene Series.

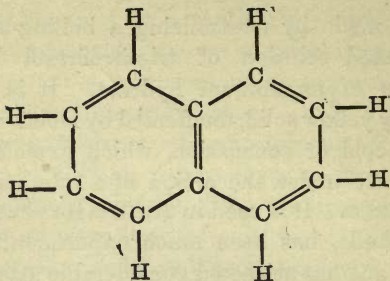
The naphthalene series comprises hydrocarbons of the general symbol



in which n is at least 10.

Derivatives of Naphthalene.

Naphthalene, $C_{10} H_8$, is the lowest member of the naphthalene series, and furnishes a series of nitro-compounds similar to those obtained from benzene and toluene. Its structural formula is:



Four degrees of nitration have been obtained.

Mono-nitronaphthalene.—Mono-nitronaphthalene, $C_{10}H_7(NO_2)$, may be prepared by introducing finely pulverized naphthalene into a mixture of four parts nitric acid (sp. gr. 1.4) and five parts sulphuric acid (sp. gr. 1.84), keeping the temperature above $160^\circ F$.

It is a yellow crystalline solid, which decomposes when heated above $300^\circ C$. It is not explosive, as may be inferred from the small proportion of oxygen in the compound, but is used in explosive mixtures.

Di-nitronaphthalene.—Di-nitronaphthalene, $C_{10}H_6(NO_2)_2$, may be made by treat-

ing naphthalene at 70° C., with a mixture of one part concentrated nitric acid and two parts sulphuric acid.

It is a yellow, crystalline solid, which deflagrates if heated suddenly.

Tri-nitro-naphthalene.—Tri-nitro-naphthalene, $C_{10}H_5(NO_2)_3$, is made by boiling di-nitro-naphthalene with fuming nitric acid.

It is a yellow crystalline solid, which explodes when heated.

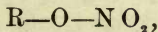
Tetra-nitro-naphthalene. — Tetra-nitro-naphthalene, $C_{10}H_4(NO_2)_4$, is made by boiling di-nitro-naphthalene with fuming nitric acid and continuing the action beyond that required to form the tri-compound.

It is a yellow crystalline solid, which explodes when heated.

All the nitro-naphthalenes are used in explosive mixtures.

5.—ORGANIC NITRATES.

The organic nitrates may be represented by the general symbol



in which R is an organic radical, and they are derived from $\text{H}-\text{O}-\text{N O}_2$ (nitric acid) by the substitution of a basic organic radical (C_3H_5 , etc.) for the hydrogen of the acid, or by the substitution of the acid radical, N O_2 , for the hydrogen of the hydroxyl of the organic compound, according to the two general methods in which all oxysalts may be conceived to be formed.

These compounds, being true nitrates, are distinguished from the nitro-substitution compounds by the fact that the N O_2 group in each is united to the carbon atom of the organic radical not directly, but through an atom of oxygen.

They may be divided into two sections:

Derivatives of the Benzene Series.

Derivatives of the Alcohol Series.

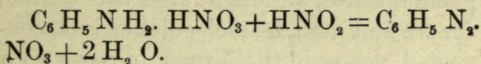
A.

Derivatives of the Benzene Series.

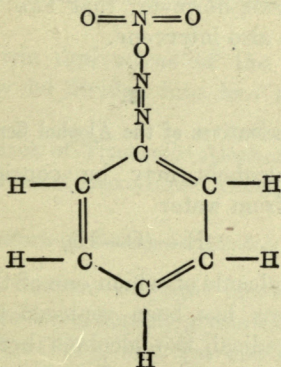
There is but one important compound in this section of explosives.

Di-azobenzene Nitrate.—Di-azobenzene nitrate, $\text{C}_6\text{H}_5\text{N}_2\text{N O}_3$, is prepared by passing nitrous acid vapor into a flask con-

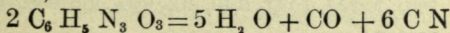
taining aniline nitrate moistened with a small quantity of water, and cooled with ice; the resulting liquid is filtered, alcohol and ether are added, and the diazobenzene nitrate separates as a crystalline mass:



Its structural formula is:



It explodes violently when heated (at $90^{\circ}\text{C}.$):



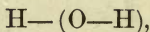
+ 5 C, and has been proposed for use as a detonating primer.

This compound is the connecting link between the nitro-compounds and the organic nitrates, although it is a true nitrate; for we find here the molecules of NO_2 connected, not as in the former, directly to a carbon atom, but as in the latter, through an atom of oxygen, with the modification in this case, however, that two atoms of nitrogen also intervene.

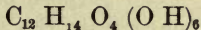
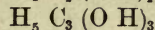
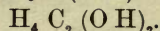
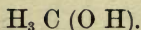
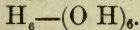
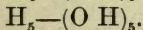
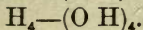
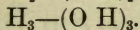
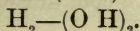
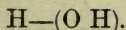
B.

Derivatives of the Alcohol Series.

The alcohols may be considered as formed from water



in the molecule of which one of the hydrogen atoms has been replaced by a compound radical, the alcohols being designated as monatomic, diatomic, triatomic, tetratomic, pentatomic, hexatomic, etc., according as they are derived from one, two, three, four, five, six, etc., molecules of water :



The alcohols may therefore be regarded as compounds of organic radicals with hydroxyl; in other words, as *organic hydroxides*.

The nitric derivatives of the alcohol series may be divided into two sub-sections:

Derivatives of Triatomic Alcohols.

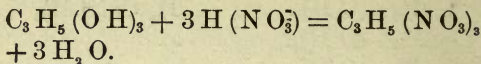
Derivatives of Hexatomic Alcohols.

a. Derivatives of Triatomic Alcohols.

There is but one triatomic alcohol that concerns us here, namely glycerine, $\text{C}_3 \text{ H}_8 \text{ O}_3$, or $\text{C}_3 \text{ H}_5 (\text{O H})_3$, and but one organic nitrate derived from it, namely glyceryl nitrate, or *nitro-glycerine*.

Nitroglycerine.—Nitroglycerine, $\text{C}_3 \text{ H}_5 \text{ O}_3 (\text{N O}_2)_3$, is prepared by treating glycerine with a mixture of nitric and sulphuric

acids, keeping the mixture cool during the conversion:



The purpose of the sulphuric acid is to concentrate the nitric acid, by absorbing the water which even the strongest commercial nitric acid always has, and keeping it concentrated by taking up the water produced in the reaction.

This absorption of water, (as well as the other chemical actions in the process) is attended by the production of heat, and at 30° C. there is danger of explosion, hence the necessity for keeping the mixture cool.

In the manufacture of nitroglycerine the purest and most concentrated materials (acids and glycerine) are used. The proportions used are about 1 part glycerine to 8 parts of a mixture of 3 parts nitric and 5 parts sulphuric acid.

The acids, if obtained separately, are run into a cast-iron mixing tank, mixed by means of compressed air, and allowed to cool for twelve or twenty-four hours.

The cooled acid mixture (which may be purchased already mixed,) is run into the *acid tank*, also of cast-iron, and the necessary amount of glycerine is introduced into the *glycerine tank*; the mixed acids are then run into the *converter*, a cast-iron vessel surrounded by a water-jacket and containing leaden worms in which water circulates, with a shaft running through the centre, on which blades are arranged to form a helical agitator; water is made to circulate through the water-jacket and the cooling-worms, and the agitator is started; the glycerine is then run into the converter, either in fine streams through a pipe perforated with small holes, or as a spray by means of compressed air.

During the conversion the temperature is carefully watched, and as it approaches 30° C. the flow of glycerine is stopped; should the temperature continue to rise the contents are emptied into the *discharge tanks*, which are lead-lined wooden tanks of large capacity, kept half filled with water.

When all the glycerine has been run in,

and the nitration is complete, the liquid is run into the *first separator*, a large vessel of sheet lead, with a conical bottom, terminated by a separatory funnel (connected for safety with the discharge tanks). The nitro-glycerine, being somewhat lighter than the excess of acids, collects on the surface and is run off by a stop-cock placed at the proper level, to the *first washing-vat*, while the waste acids are run out to a *second separator* of similar action, the separatory funnel separating a little more of the nitro-glycerine, which is added to that already in the first washing-vat.

In the first washing-vat (a lead-lined wooden vessel, with an inclined bottom through which passes a leaden pipe with a rosette head for admitting compressed air), the nitro-glycerine is covered with a large volume of water, while it is being agitated by means of compressed air admitted below; the water is changed four or five times, a stop-cock being placed at the proper level to run it off; the washing at this stage is then completed by using a $2\frac{1}{2}$ per cent. solution of

sodium carbonate; the nitro-glycerine is finally run off, by a tap at the bottom of the vat, to the *second washing-vat*, similar to the first, but fitted with an agitator, where the washing is completed.

If the nitro-glycerine is to be used for making dynamite, it is run directly to the mixing house, but if it is not to be used immediately it is stored in lead-lined wooden tanks.

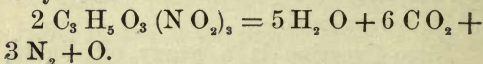
If the nitro-glycerine is to be used in making explosive gelatine or smokeless powder, it is usually run from the second washing-vat to the *filter*, a lead-lined wooden vat, the top of which is fitted with a copper or lead cylinder, containing first a wire-gauze disk, over which is placed a second disk of felt, and upon this a compact layer of common salt, about five inches thick, covered with another felt disk and a second wire-gauze disk. The bottom of the vat is inclined and has a tap for running off the filtered nitro-glycerine at its lowest level.

Nitro-glycerine is a heavy, oily liquid, (sp. gr. 1.6), generally opaque and creamy

white, or clear and transparent, sometimes yellowish. It is slightly soluble in warm water, but is unaffected by cold water; it is soluble in methyl, ethyl, or amyl alcohol, in benzene, carbon disulphide, ether, chloroform, glacial acetic acid and phenol, and also sparingly in glycerine. It is decomposed by dilute sulphuric acid (hence the necessity for such careful washing in its manufacture), by ammonia, and by alkaline carbonates and sulphides.

It freezes to a white crystalline mass (the opaque variety at 20° C., the transparent at $+3^{\circ}$ C.), and is then less sensitive to concussion. Frozen nitro-glycerine is thawed by placing it in a room where the temperature does not exceed 50° C., or in the field or in mines by means of the water-bath devised for the purpose.

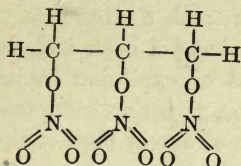
It explodes by percussion, or when heated to 180° C., but the best effects are produced by means of detonators of mercury fulminate:



From the reaction it is seen that this

explosive contains more oxygen than is necessary for the complete oxidation of both the hydrogen and the carbon.

The structural formula is:



and the energy of explosion is again explained by the fact that the elements of highest affinity, hydrogen and oxygen, are held apart in the molecule, whereas in the products they are united, and the affinity of the carbon atoms for oxygen is only partially satisfied in the molecule, whereas in the products it is completely satisfied.

Nitro-glycerine, at ordinary temperatures, and in the dark, is quite stable, but a temperature of over 50° C. slowly decomposes it, and the direct rays of the sun have the same effect. When in a state of decomposition, due to physical or chemical causes, it becomes much more sensitive to various causes of explosion.

Comparing the structural formulæ of glycerine and nitro-glycerine it is evident that the latter is a *tri*-nitrate, and it is supposed that it is possible to obtain a mono-nitrate and a di-nitrate, although they have not as yet been isolated. One of the causes of explosion in improperly prepared nitro-glycerine is supposed to be the presence of one or both of these lower products of nitration.

b. Derivatives of Hexatomic Alcohols.

The following hexatomic alcohols have furnished explosive nitrates:

Mannite, $C_6 H_{14} O_6$, or $C_6 H_8 (O H)_6$ and
Cellulose, $C_{12} H_{20} O_{10}$, or $C_{12} H_{14} O_4 (O H)_6$,

but the following derivatives of mannite (all of them carbo-hydrates) have also furnished such nitrates:

Glucose, $C_6 H_{12} O_6$, an aldehyde of mannite, obtained by oxidising and removing from the molecule of the latter two atoms of hydrogen.

Starch, $C_{12} H_{20} O_{10}$, an anhydride of glu-

cose, obtained by removing a molecule of water from the molecule of the latter.

Saccharose, $C_{12} H_{22} O_{11}$, an anhydride of glucose, obtained by removing a molecule of water from two molecules of the latter.

Lactose, $C_{12} H_{22} O_{11}, H_2 O$, derived in the same way, but taking up a molecule of water of crystallization.

Only a few of these nitrates have proven of practical value.

Nitro-mannite. — Nitro-mannite, $C_6 H_8 (N O_3)_6$ is prepared by adding powdered mannite to a mixture of equal parts by volume of the strongest nitric and sulphuric acids; the result is washed with a large volume of water, and crystallized from boiling alcohol.

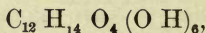
It explodes violently by percussion.

Nitro-starch. — Nitro-starch, $C_{12} H_{14} O_4 (N O_3)_6$, is prepared by dissolving starch in the strongest nitric acid, and then adding the solution, when cool, to a mixture of nitric and sulphuric acids.

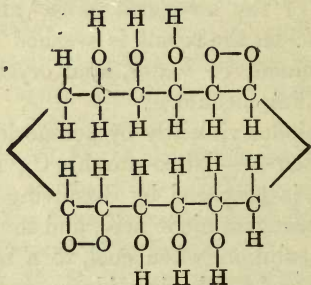
It is very hygroscopic and liable to undergo spontaneous decomposition; it is insoluble in water, but soluble in nitroglycerine, in acetic ether, and in a mixture of ether and alcohol.

Two other nitrates, besides the hexanitate, namely, the tetranitrate (formerly called *xyloidine*) and the pentanitate, have been obtained.

Nitro-Cellulose.—The most reliable investigations on the constitution of cellulose and its nitrates indicate that the former is a hexatomic alcohol,

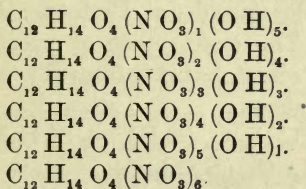


and its structural formula may be:



Whether the above be the true symbol for cellulose, or the latter be some higher multiple of $C_6 H_{10} O_5$, the structural formula will probably still contain in each link of the chain of atoms an arrangement of atoms something like the above, because it is fairly well established that in each such link three of the hydrogen atoms are connected to carbon atoms through an atom of oxygen, and not more than three.

Accepting the above as the true formula it is evident that the following nitrates may be formed, by substitution of one or more molecules of NO_3 for one or more molecules of hydroxyl:



The lower nitrates are designated by the general terms *soluble nitro-cotton* or *colloidion gun-cotton*, and are soluble in a mixture of alcohol and ether; the pentanitrate

is one of the forms of nitro-cotton employed for smokeless powders; and the hexa-nitrate is guncotton, which is insoluble in a mixture of alcohol and ether.

As in the preparation of other compounds of this kind, the degree of nitration depends upon the strength of the acids used, and on other precautions taken in the manufacture. For the highest degree the purest materials and the strongest acids are required.

Pyrocollodion.—Pyrocollodion, $4 [C_{12} H_{14} O_4 (N O_3)_5 (O H)] + 1 [C_{12} H_{14} O_4 (N O_3)_4 (O H)_2]$, or (if it be a true compound), $C_{30} H_{38} O_{13} (N O_3)_{12}$, is the new Russian smokeless powder of Professor D. Mendeléef. The exact mode of preparation is still a secret, but it is formed according to the reaction:

$5 [C_{12} H_{14} O_4 (O H)_6] + 24 H N O_3 = 2 [C_{30} H_{38} O_{13} (N O_3)_{12}] + 24 H_2 O$, or, if the result be a *mixture* of tetra and penta nitrates, in constant proportion, instead of a simple *compound*:

$= 4 [C_{12} H_{14} O_4 (N O_3)_5 (O H)_1] + 1 [C_{12} H_{14} O_4 (N O_3)_4 (O H)_2] + 24 H_2 O$.

This explosive is insoluble in ether or alcohol, but wholly soluble in a mixture of these substances, and gelatinises when the quantity of the solvent is small. It can be converted into ribbons or plates, which, when dried, have the appearance of celluloid. It keeps well, and can be heated to 65.°5 C. for hours without undergoing any change.

But the great advantages claimed for it are:

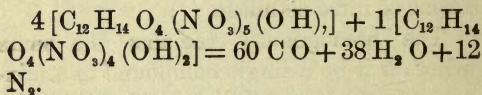
1. *Homogeneity* of composition, which determines directly the *uniformity* of the ballistic results obtained.

2. The development of a *greater volume of gases* (measured at a given temperature and pressure) than is developed by black or brown powder, by nitro-glycerine powders, or even by the more highly nitrated forms of nitro cellulose.

The homogeneity remains the same whether it be a single compound or a mixture of two compounds, provided this mixture is always fixed and definite, and formed, not by mechanically mixing two separately prepared compounds, but by a

single chemical reaction. The other forms of nitro-cellulose almost always contain more or less of the less highly nitrated products, and all mechanical mixtures are, of course, much less homogenous in a chemical sense, while the nitro-glycerine powders, consisting of nitro-cellulose dissolved in nitro-glycerine, though apparently as homogeneous as solutions can be by their action nevertheless leave room for believing that in their explosion the nitro-glycerine is decomposed first, the nitro-cellulose portion burning subsequently. The results of the published experiments are greatly in favor of pyrocollodion, both as regards progressiveness and uniformity of action.

The explosion of pyrocollodion may be represented by the reaction:

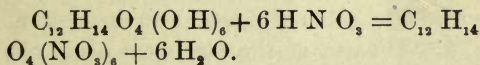


The volume of gas (measured at a fixed temperature and pressure) from 1,000 parts by weight of the explosive is 81.5,

whereas that from the same weight of brown powder is about 34, from nitro-glycerine 52.7, and from the hexanitrate (guncotton) 74.1.

The experiments with the 3 pounder (47 mm.) rapid fire gun show that with a pressure of 2079 atmospheres an initial velocity of 699 m. (2293') was attained. In the 6 pounder, (projectile weighing about 40 kg.) an initial velocity of 878 m. (2880.5') was obtained, although the average for this gun was about 792 m. (2598').

Guncotton.*—Guncotton, $C_{12} H_{14} O_4 (NO_3)_6$, is the nitric ether of cellulose, the latter being regarded as a hexatomic alcohol, $C_{12} H_{14} O_4 (OH)_6$. It is prepared by treating cellulose with a mixture of nitric and sulphuric acids:



The sulphuric acid serves the same purpose in this case as in the manufacture of nitro-glycerine.

* See Number 89, *Van Nostrand's Science Series*.

The principles upon which its manufacture depends are: (1) the thorough cleansing of the cotton; (2) its thorough drying, (less than 0.5 per cent. of moisture being permissible); (3) the cooling of the cotton; (4) the use of the strongest acids obtainable in commerce; (5) the continuance of the steeping for at least 12 hours; (6) the thorough purification of the guncotton from every trace of free acid.

The process of manufacture, as conducted at the U. S. Naval Torpedo Station, is as follows:

The principles upon which its manufacture depends are:

1. The thorough cleansing of the cotton.
2. Its thorough drying.
3. The cooling of the clean dry cotton.
4. The use of the strongest acids obtainable in commerce.
5. The continuance of the steeping for at least twelve hours.
6. The thorough purification of the guncotton from every trace of free acid.

The process of manufacture, as conduc-

ted at the U. S. Naval Torpedo Station is as follows:*

The cotton clippings from the spinning-room are first sorted by hand, and then pass to the first boiling tub, where 200 pounds are boiled in caustic soda solution for about 8 hours; after the first boiling the liquid is run off, clear water is added, and the boiling continued for 8 hours more. The wet cotton is then taken to the first centrifugal washer (making about 1400 revolutions a minute), in which about 6 pounds of the cotton at a time are washed in a stream of water, each charge requiring about 8 minutes, and the entire mass about 2 hours.

The washed cotton is then placed in the drying room, on shelves of galvanized iron wire netting, and dried by hot air, the temperature being kept at about 187° F.; this takes about 4 days. The dried cotton is then placed in the picker, (like that used in cotton mills), where it is loosened

* For full and clear description of the process see *Lectures on Explosives*, WALKER.

and untangled, and is then further dried by hot air at 225° F., in galvanized iron drawers with wire-netting bottoms, in the drying closet. It is packed while still hot into service powder-tanks, the covers screwed on, and the cotton allowed to cool.

When cool it is ready for dipping, which takes place in the dipping-troughs, of which there are five, each holding about 150 pounds of mixed acids: they are made of cast-iron, and set in an iron trough where they are kept below 70° F. by circulating water. The acids are obtained ready mixed, one part by weight of pure nitric acid (sp. gr. 1.5) to three parts by weight of sulphuric acid (sp. gr. 1.845), and are transported in wrought-iron cylindrical drums, each holding about 1200 pounds, and pumped into stoneware reservoirs, where they are led to the dipping troughs. The first of the troughs is used as a reservoir for the acid to be immediately used, the other four for dipping.

The cotton is weighed out in one-pound lots, and each lot is divided into three

equal parts, each part being worked into the acid in turn by means of a steel fork, and stirred about. As soon as the fourth trough has its charge the cotton is taken out in the same order and placed on the grating above each trough, where it is squeezed by means of a lever-press and is then placed in the digestion-pots (two-gallon stone-ware crocks) the covers of which are put on; finally, the pots are placed in water in a cooling-trough and left over night.

The digestion-pots are drained and dried externally, and two pots full of guncotton at a time are partially freed from acid in a centrifugal acid-wringer; after which the guncotton is fed, little by little, into the immersion-tub, of 800 gallons capacity, through which water flows at a rapid rate, the guncotton being carried quickly under water by a cylindrical wooden drum rotating on a horizontal axis. Fifty crocks are thus emptied into the tub. The guncotton is then placed on a wooden rack to drain.

After draining, the entire mass is placed

in the second boiling-tub (of 300 gallons capacity), which is heated by a steam-coil placed under a false bottom in the tub, and boiled for eight hours in water containing 10 pounds of sodium carbonate; it is then allowed to drain overnight, washed with fresh water in a centrifugal wringer, again boiled in the boiling-tub, drained, and washed as before.

The guncotton is next fed into the pulper, the ordinary rag engine of the paper-mills, where it is cut to the fineness of corn meal. The pulp is then run into the poacher, a large wooden tub, in which a cylinder armed with wooden feathers rotates the mass and keeps the guncotton in suspension in the water, the guncotton being allowed to settle and drain every hour, fresh water added, and the operation repeated and continued for about two days. When the washing is completed (which is determined by a test) there is added 3 pounds of precipitated chalk, 3 pounds of caustic soda, 300 gallons of lime water, and water enough to bring the entire mass to 800 gallons; and by means

of a vacuum-pump this is raised into the stuff-chest, a cylindrical iron tank, through the center of which passes a vertical shaft, with feathers, geared to a horizontal shaft, serving as a stirrer to keep the contents uniformly mixed. The pulp is transferred to the wagon, a cylindrical copper vessel, holding 25 gallons, in which a stirrer is also kept going, while it moves on rails from the stuff-chest to the moulding-press, in which the guncotton is pressed into blocks, 2.9 inches square and two inches high, which are finally completed in the final-press.

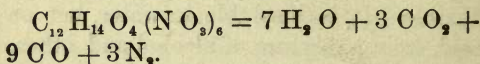
These guncotton blocks contain about 14 per cent. of moisture; and before being sent out into service they are placed in troughs of water till they cease to absorb any more, when they contain about 35 per cent.

Guncotton in the fibrous state is very like the cotton from which it is made, in appearance, but feels harsher and less flexible. It is insoluble in water, hot or cold, or in a mixture of alcohol and ether, but soluble in ethyl acetate, in acetone,

and in a mixture of ether and ammonia. When dissolved in caustic alkali solutions the cellulose may be precipitated in a flocculent form by neutralizing the alkali. In the fibrous or flocculent state its density is not over 0.3, but by pressure it may be increased to 1.5. Air-dried guncotton contains about 2 per cent. of moisture.

It explodes at about 182° C. The impurities in the cotton fibre, under the action of nitric acid, give rise to the nitrogenized substances which cause the decomposition of guncotton by first forming free acid: the effect of this action is neutralized by mixing with the guncotton a small percentage of sodium carbonate. Wet guncotton is perfectly safe, and can only be exploded by means of a primer of dry guncotton while the best effects of dry guncotton are obtained by a detonator of mercury fulminate.

The explosion of guncotton is practically represented by the equation:



594 parts by weight = $7 \times 2 + 3 \times 2 + 9 \times 2 + 3 \times 2 = 44$ volumes.

$594 : 1000 :: 44 : V_{1000} = 74.1$ volumes.

The reaction shows that guncotton is deficient in oxygen, since only part of the carbon is oxidized to carbon dioxide, a large proportion remaining as carbon monoxide.

Nitro-Hydrocellulose.—Nitro-Hydrocellulose is a guncotton prepared by steeping cotton for a few minutes in an acid mixture of 3 parts sulphuric acid (sp. gr. 1.84) or 3 parts hydro-chloric acid (sp. gr. 1.20) to 97 parts water, washing and drying. The pulverulent hydro-cellulose is then nitrated in the usual way. The nitro-hydrocellulose is used for making primers for blasting gelatine.

II. MIXTURES.

CONTAINING NITRO-COMPOUNDS OR ORGANIC NITRATES.

The principles on which mixtures of this class are based are:

1. Some of the nitro-compounds or organic nitrates have in themselves an insufficient supply of oxygen for complete oxidation, hence the advantage of mixing oxidizing agents with them.

2. Some of the nitro-compounds or organic nitrates have in themselves an insufficient supply of oxygen for complete oxydation, while others have an excess, hence the advantage of mixing them in proper proportions.

3. Some of the nitro-compounds or organic nitrates are liquid, which is a disadvantage in many ways, hence they are mixed with solids, which absorbs the liquid, and convert the whole into a solid mass. The solids used may be (*a*) inert bodies, which merely act like a sponge and render the explosive less sensitive but also less powerful; (*b*) low explosives, which permit a lower percentage of the liquid explosives being used than the inert bodies; (*c*) high explosives, which, of course, increase the effect of explosion.

4. Some of the nitro-compounds (as well as other substances) act as deterrents,

and are therefore added to high explosives when a comparatively slow action is required.

5. Some of the nitro-compounds (as well as other substances) lower the freezing point of the liquid organic nitrates, and are added to prevent the freezing of the latter.

6. Some of the liquid nitro-compounds or organic nitrates gelatinize solid organic nitrates, and thus place them in a physical condition by which the rate of combustion may be regulated and controlled.

7. In coal mines a special quality is desirable in the explosive to be used, namely, that it shall not readily fire the mine. The ordinary gunpowders, as well as nitroglycerine, dynamite, etc., as usually prepared, are found to cause explosions of mines by setting fire to the explosive mixture of marsh gas and atmospheric air often present, or to the finely divided coal dust very commonly disseminated through the air of such a mine. Now, it has been found that explosive mixtures (blasting powders) do this in varying de-

grees, much greater weights of some than of others being required for the purpose.

The explanation of this action is not far to seek. It is well known that to explode a mixture of marsh gas and air requires a *high temperature* (that corresponding to the white heat of solids), consequently it must be in contact with flame for a certain *time* in order to have its temperature raised to the point of ignition.

Now, in the case of ordinary gunpowder and the low explosives generally, the temperature of explosion, although not very high, is yet high enough, and the slowness of the action gives the necessary time for the explosion of the gaseous mixture. Again, in the case of the ordinary high explosives, the temperature of explosion is so high that little time is required, and the same effect is produced, whereas, in the case of certain mixtures (safety blasting powders), which have thus far been determined only by experiment, the temperature is kept down, but the quickness of action is not interfered with, so that, at the temperature of explosion (of the

blasting powder) reached, firing of the mine does not take place. Of course the sudden rapid motion of the air, consequent on the explosion of the blasting powder, also prevents the temperature of any particular portion rising to the point of ignition.

1.—NITROBENZENE MIXTURES.

Containing no other nitro-compound and no organic nitrate.

The nitrobenzene mixtures are all based on the fact that the nitrobenzenes are deficient in oxygen, and are consequently made more efficient as explosives by the addition of oxidising agents.

Bellite.—Bellite is a Swedish powder made by fusing together dinitrobenzene and ammonium nitrate, pressing and granulating the fused mass. It is plastic and can be pressed into cartridges; it is somewhat hygroscopic. It is safe against friction, heat, or the explosion of gunpowder, and can be exploded only by detonators.

The explosion is accompanied by very

little flame, and for the older proportions of 1 part meta-dinitrobenzene and 5 parts ammonium nitrate may be represented by:

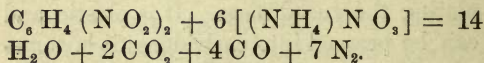
$$\text{C}_6\text{H}_4(\text{N O}_2)_2 + 10 [(\text{N H}_4) \text{N O}_3] = 22 \text{H}_2\text{O} + 6 \text{C O}_2 + 11 \text{N}_2.$$

For the best blasting powders the proportions are:

Bellite No. 1.—82 ammonium nitrate 18 dinitrobenzene.

Bellite No. 3.—95 ammonium nitrate 5 dinitrobenzene.

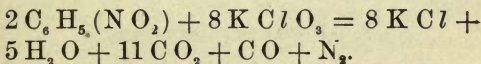
Securite.—Securite is composed of 26 parts of meta-dinitrobenzene and 74 parts of ammonium nitrate, although later varieties contain the trinitrobenzene as well, and *Flameless Securite* contains an addition of ammonium oxalate. It is a bright yellow granular solid, not hygroscopic, and high in explosive force. Its explosion is represented by:



Rack-a-Rock.—Rack-a-Rock is an explosive of the Sprengel Class, the separately transported constituents being mononitro-

benzene (21 parts) and potassium chlorate (79 parts). In preparing the explosive the chlorate cartridges are placed in cells in a pan, and the proper amount of the liquid is poured over each. When ready for use it is still quite safe to handle, since ordinary friction has little tendency to explode it.

The reaction of its explosion is approximately:



This is the explosive which was used in the removal of Flood Rock.

Hellhoffite.—Hellhoffite is another explosive of the Sprengel Class, the constituents being meta-dinitrobenzene (47 parts) and nitric acid (sp. gr. 1.50, 53 parts).

It is a powerful explosive, but the nitric acid is difficult to transport and to store. If water be added to the mixture it becomes nonexplosive, which is an advantage in general, but, of course, prevents its use under water.

Roburite.—Roburite, a blasting powder, is made in several grades:

	No. 1.	No. 3.
Ammonium nitrate, -	87.7	87.5
Dinitrobenzene, - - -	7.2	7.0
Potassium permanganate,	5.1	0.5
Ammonium sulphate, —		5.0

Some varieties contain about 2 per cent. of chloronaphthaline.

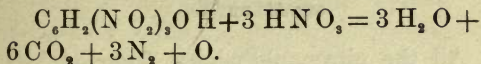
2.—PICRATE MIXTURES.

Containing no other nitro-compound and no organic nitrate.

The principle of these mixtures is that the picrates have not sufficient oxygen, and can therefore be made efficient as explosives by adding oxidizing agents.

Oxonite.—Oxonite, an explosive of the Sprengel Class, consists of picric acid packed in a calico cartridge, in which is placed a hermetically sealed glass tube containing nitric acid: the tube is broken by a blow before inserting the cartridge. It resembles hellhoffite, but is not so pow-

erful, and requires a very powerful detonator.



Designolle's Powder.—Designolle's powder, manufactured at Le Bouchet, France, consists of potassium picrate, potassium nitrate and charcoal, prepared like ordinary gunpowder. The proportions for small arms are 28.6, 65.0, and 6.4; for heavy guns 9, 80, 11; for torpedos and shells, 55, 45, 0.

Emmensite.—Emmensite is made by fusing very pure picric acid, and dissolving in it sodium nitrate and ammonia nitrate. It has been used in mining with excellent results.

Several other powders of this group have been proposed (Abel's, Brugère's, Fontaine's, Borlinetto's) but none of them has proven of practical value.

3.—NITRONAPHTHALENE MIXTURES.

Containing no other nitro-compound and no organic nitrate.

All the nitronaphthalenes form explosives when mixed with oxydising agents.

Volney Powders.—Volney powders are mixtures of nitronaphthalene with potassium nitrate and sulphur, prepared like ordinary gunpowder. The two principal varieties are:

	No. 1.	No. 2.
Mononitronaphthalene, 1 part.		
Tetranitronaphthalene, -	2.18	parts.
Potassium nitrate, 3.30 “	0.19	“
Sulphur, - - - - 0.51 “	0.16	“

They are insensitive to friction or heat, and require a powerful detonator.

Favier Powders.—Favier Powders, Ammonites or Nitramites, are mixtures of nitronaphthalenes, with ammonium nitrate, and are manufactured at Saint-Denis, France. The ammonium nitrate is first dried by passing it on an archimedes screw through a trough warmed by steam; it is then pressed, and sprinkled with melted ni-

tronaphthalene, and the roll thus formed is granulated, the coarser grains being moulded warm into hollow cartridges and covered with paraffin, while the smaller are packed in the core; the detonator is then inserted and the whole covered with paraffin paper. The principal objection to these powders is the hygroscopic character of the ammonium nitrate.

The best variety consists of 87.5 parts ammonium nitrate and 12.5 parts dinitronaphthalene.

Grisoutine Roche.—Grisoutine Roche, one of the four mixtures now principally employed in mining operations in France, contains dinitronaphthalene (9.5 parts) and ammonium nitrate (90.5 parts).

4.—NITROGLYCERINE MIXTURES.

Containing no nitro-compound and no other organic nitrate.

DYNAMITES.

The object in view in making nitro-glycerine mixtures is to overcome the dis-

advantages of the *liquid* state of this explosive compound, and to utilize the excess of oxygen it contains. They are called *Dynamites* as a class, and the base (or porous solids for absorbing the liquid) may be either inert or active.

An inert base acts purely mechanically, absorbing the liquid nitroglycerine and converting it into a *solid* mass, whereas an active base takes part chemically in the explosion, besides acting as a mechanical absorbent. The effect of the inert base is to render the nitroglycerine less sensitive, but it also diminishes its explosive force. Advantage is taken of this latter fact to make dynamites of various grades, by varying the amount of nitroglycerine.

However, there is a minimum limit to this, for a dynamite with an inert base cannot be exploded when the percentage of nitroglycerine falls below 30. In order to make dynamites of lower grade, a low explosive mixture is used as the absorbent, in which case the percentage of nitroglycerine may be brought as low as 5.

To utilize the excess of oxygen present, some oxidizable substance (usually a form of carbon) is added.

Finally, to convert the liquid explosive into a solid mass, and at the same time increase its explosive power above that of dynamite with an inert base, a low explosive base is used; and to increase its explosive power above that of nitroglycerine itself, a high explosive base is used: in the former the detonation of the nitroglycerine causes the *detonation* of the low explosive mixture with increased effect, and in the latter the high explosive is, of course, detonated, and thus causes the great power of such a mixture. The members of this last group are not usually called dynamites, and are here placed in separate classes, depending on the high explosive used as a base.

Dynamite No. 1.—Dynamite No. 1, a dynamite with an inert base, consists of a mixture of 25 parts of Kieselguhr, (a siliceous earth, composed mainly of the shells of diatoms) and 75 parts of nitroglycerine.

The Kieselguhr is first calcined in a reverberatory furnace, then crushed between rollers, passed through fine sieves, dried, packed in bags and stored in a dry place; when required for use it is weighed out in proper quantity, placed in lead-lined tanks, and the proper amount of nitroglycerine poured over it; the ingredients are thoroughly mixed by hand, the mass being finally rubbed through sieves.

For blasting, the dynamite is made into cylindrical cartridges, $\frac{3}{4}$ to 1 inch in diameter, 2 to 8 inches long, in a press, and these cartridges are wrapped in paraffined paper or in parchment paper. For military purposes, dynamite is packed in water-proof metallic cases, or in rubber bags.

Dynamite is a granular, plastic substance, which may explode at 180° C.; it freezes at 4° C., and can then be detonated only with great difficulty. When heated, or when in a state of decomposition, it becomes very sensitive to shock, although generally quite stable and less sensitive than nitroglycerine.

Dynamite No. 1 is used for charging torpedoes and for blasting. It is the standard high explosive used by the U. S. Engineers.

Giant Powder No. 1.—Giant Powder No 1, another dynamite with an inert base, but with a small quantity of deterrent added, is composed of 75 parts nitroglycerine, 24.5 Kieselguhr, 0.5 sodium carbonate.

Wetterdynamite.—Wetterdynamite, similar in character, but with a much larger quantity of deterrent, is an explosive which has been found by recent experiments in Austria to be very safe for use in coal mines, as it is little apt to fire either the explosive mixture of marsh gas and air, or the finely divided coal dust disseminated through the air in the mine.

The best composition is:

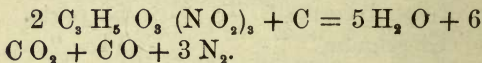
Nitroglycerine	-	-	52 parts.
Kieselguhr,	-	-	14 “
Sodium carbonate crystals,			34 “

Grisoutine.—Grisoutine, one of the mixtures now chiefly employed in mining operations in France, contains ammonium

nitrate (60 parts) and dynamite No. 1 (40 parts).

Nobel Ardeer Powder.—Nobel Ardeer Powder consists of 32 parts of nitroglycerine, 13 parts of Kieselguhr, 49 of magnesium sulphate, 5 parts of potassium nitrate, 0.5 parts of ammonium carbonate, and 0.5 parts calcium carbonate.

Carbodynamite.—Carbodynamite, a dynamite with an active base that is merely oxydisible, with a view to utilizing the excess of oxygen in the nitroglycerine, consists of nitroglycerine (90 parts) and carbonized cork (10 parts), with 1.5 per cent. of ammonium carbonate added to the mixture. It is a black, friable solid, which, when used under water does not permit the nitroglycerine to exude. Its explosion is thus represented:



Dynamite No. 2.—Dynamite No. 2, a dynamite with a low explosive mixture as a base, consists of nitroglycerine (18 parts), potassium nitrate (71 parts), charcoal (10

parts) and paraffin (1 part). It is a much milder dynamite than No. 1.

Dualin.—Dualin, another dynamite with a low explosive base, is composed of nitroglycerine, potassium nitrate and sawdust (50 : 20 : 30).

Giant Powder No. 2.—Giant powder No. 2, of similar character, contains :

Nitroglycerine, 40 parts. Sodium nitrate 40 parts. Kieselguhr, 8 parts. Sulphur, 6 parts. Resin, 6 parts.

Vulcan Powder.—Vulcan powder is also a dynamite of low explosive base: nitroglycerine 30 parts, sodium nitrate 52.5 parts, charcoal 10.5 parts, sulphur 7 parts.

Atlas A Powder.—Atlas A Powder is composed of nitroglycerine (75 parts), sodium nitrate (2 parts), magnesium carbonate (2 parts) and wood-fibre (21 parts).

Carbonite.—Carbonite, or Kohlencarbonit, for colliery purposes, is composed of:

Nitroglycerine, 25.0.

Potassium nitrate, 34.0.

Rye flour, 38.5.

Barium nitrate, 1.0.

Oak bark powder, 1.0.

Sodium carbonate, 0.5.

In England it has been found relatively one of the safest explosives for use in coal mines: 900 grams was the maximum charge required to explode a test mixture of marsh gas and air, while gelatine dynamite required only 30, and Cologne-Rottweiler 500. Its force, compared with gelatine dynamite, is 0.405 : 1.

Vigorite.—Vigorite, manufactured by the California Vigorite Powder Company, is a dynamite with a low explosive (chlorate mixture) base, of the following composition:

Nitroglycerine, 30.

Potassium chlorate, 49.

Magnesium carbonate, 5.

Potassium nitrate, 7.

Wood pulp, 9.

Hercules Powder.—Hercules powder is very similar:

Nitroglycerine, 40.

Potassium chlorate, 3.34.

Magnesium carbonate, 10.

Potassium nitrate, 31.

Sugar, 15.66.

Other powders of this section are Aetna, Atlas, Judson, Rendrock, American Safety, Stonite, Horsley, Hecla, etc.

5.—NITROGLYCERINE AND NITROBENZENE MIXTURES.

Containing no other nitro-compound or organic nitrate.

There is but one mixture belonging to this section that has attained any importance, and the principle involved in its preparation is that nitrobenzene lowers the freezing point of nitroglycerine, and acts as a deterrent, retarding explosion.

Castellanos Powder.—Castellanos Powder, in one of its forms, consists of nitroglycerine with nitrobenzene (to render it less liable to freeze and slower in explosion), fibrous material, and pulverized Kieselguhr.

6.—NITROGLYCERINE AND PICRATE MIXTURES.

Containing no other nitro-compound or organic nitrate.

The principle involved in such mixtures is merely that of dynamites with high explosive base.

Castellanos Powder.—Castellanos Powder in one of its forms consists of:

Nitroglycerine,	40	Sodium nitrate,	25
Picrate,	- - 10	Sulphur,	- - 5
Insoluble salt,	10	Carbon,	- - 10

The insoluble salt may be an insoluble silicate, carbonate or oxalate, etc., or generally one which does not undergo energetic chemical reaction with nitroglycerine or carbon, its purpose being to render the explosive safer.

7.—GUNCOTTON MIXTURES.

Containing no other organic nitrate and no nitro-compound.

The principles involved in these mixtures are:

(1) Certain substances (urea, resin, paraffin, aurine, humus, etc.) diminish the sensibility to shock and retard the rate of combustion.

(2) Since the supply of oxygen is deficient, the addition of nitrates is advantageous.

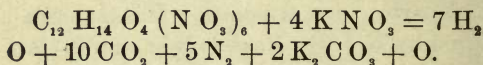
Maxim-Schüpphaus Powder. — Maxim-Schüpphaus Smokeless Powder, in one of its forms, consists of guncotton, 80 parts; soluble nitrocotton (gelatine pyroxylin), 19.5 parts; urea, 0.5 parts. It is manufactured by E. I. Du Pont de Nemours & Co., Wilmington, Delaware.

Swiss Normal Powder. — Swiss Normal Powder, the smokeless powder which has been adopted by the Swiss army, is manufactured in Sweden, and consists of 96.21 parts guncotton, 1.80 soluble nitrocellulose, 1.99 resin. It is light yellow in color, very stable, unaffected by moisture, insensitive to shock and without injurious effect on the gun.

Poudre B. — Poudre B, or Vielle's Powder, is the smokeless powder used in the French Lebel rifle, and consists of 68.21

parts guncotton, 29.79 parts soluble nitrocellulose, and 2 parts paraffin, the mixture being rolled into sheets, which are cut into little squares. It has the consistency of rubber, is pale yellow in color and translucent, and gives a high initial velocity with a low pressure.

Potentite.—Potentite consists of a mixture of guncotton (59.5 parts), and potassium nitrate (41.5 parts). Explosion reaction:

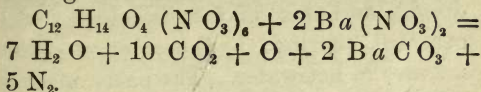


Sevran Livry Explosive.—Sevran Livry Explosive contains tetranitrocellulose (15 parts) and ammonium nitrate (85 parts). It is one of the four mixtures now mainly employed in mining operations in France.

Tonite.—Tonite, or Cotton Powder No. 1, an explosive manufactured by the Tonite Powder Company of San Francisco, California, consists of 52.5 parts pulverulent guncotton and 47.5 parts barium nitrate.

It is a white, dense solid, not sensitive

to shock, and requiring an exceptionally strong detonator.



Cotton Powder No. 2.—Cotton Powder No. 2 is composed of guncotton, a nitrate or mixture of nitrates, and charcoal.

Troisdorf Powder.—Troisdorf Powder, the smokeless powder adopted by the German army, is composed of gelatinized nitrocellulose and metallic nitrates, the mixture being rolled into sheets and then granulated.

U. S. Naval Smokeless Powder.—The smokeless powder adopted by the U. S. Navy consists of 80 parts soluble and insoluble nitrocellulose (average 12.75 per cent. nitrogen), 15 parts barium nitrate, 4 parts potassium nitrate, 1 part calcium nitrate. The solvent used in making the powder is composed of 2 parts ethylic ether (sp. gr. 0.72) and 1 part ethyl alcohol (95 per cent).

The soluble and the insoluble nitrocellu-

loses (dried separately and sifted) are mixed with the calcium carbonate (also dried), and this mixture is added (with constant stirring) to the solution of the nitrates in hot water. The pasty mass is dried at not over 48° C., and placed in the kneading-machine, where the ether and alcohol mixture is added, and the whole kneaded; after which it is pressed, first into cylinders, then into ribbons, which are cut into short lengths, the dimensions of the leaflets varying with the caliber of the gun in which they are to be used, and carefully dried.

Poudre B N.—Poudre B N is a modification of Poudre B, and consists of 29.13 parts insoluble nitrocellulose, 41.31 parts soluble nitrocellulose, 19 parts barium nitrate, 8 parts potassium nitrate and 2 parts sodium carbonate.

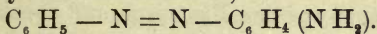
Schultze Powder.—Schultze Powder, the type of the smokeless sporting powders, is composed (according to the analyses made by Professor Munroe) of insoluble nitrocellulose (32.66 parts), soluble nitrocellulose (27.71 parts), cellulose (1.63 parts),

barium nitrate (27.62 parts), sodium nitrate (2.47 parts), paraffin (4.20 parts).

8.—GUNCOTTON AND AZO-COMPOUND MIXTURES.

The principle involved in these mixtures is merely the deterrent effect of the azo-compound, combined with the physical form given to the resulting explosive.

Rifleite.—Rifleite is a smokeless powder, made by the Smokeless Powder Company, Barwick, Herts, England, for use in the small caliber Lee-Metford Rifle. It is composed of 74.6 parts guncotton, 22.48 parts soluble nitrocellulose, and 2.52 parts phenyl amidoazobenzene,



It is a yellowish colored flake powder.

9.—GUNCOTTON AND NITROBENZENE MIXTURES.

Containing no other organic nitrate or nitro-compound.

The principle involved in these mixtures is the gelatinizing of the guncotton by

means of the nitrobenzene, and thus putting it in a physical state which enables us to control its rate of combustion.

Indurite.—Indurite, a smokeless powder invented by Professor C. E. Munroe, is prepared by colloidizing guncotton (free from soluble nitrocellulose) by means of nitrobenzene: one part of guncotton is dissolved in 1 to 2 parts of nitrobenzene; the paste resulting is run through rollers and granulated, or passed through dies and made into threads, and the powder is then subjected to the action of steam, which hardens it.

Cotton Powder No. 3.—Cotton Powder No. 3 is made by the Tonite Powder Company of San Francisco, and consists of purified metadinitrobenzene, purified guncotton, and one or more of the following: nitrate of potassium, sodium or barium, and chalk.

10.—GUNCOTTON AND PICRATE MIXTURES.

Containing no other organic nitrate or nitro-compound.

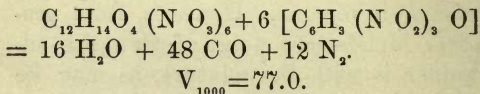
The principle involved in these mixtures is not evident, since both ingredients are deficient in oxygen. However, from professor Mendeléef's point of view the advantage is with the mixture, as may be seen by comparing the volumes of gases (measured at any fixed temperature and pressure) from 1000 parts by weight of the explosive:

Guncotton,	-	-	-	-	74.1
Picric acid,	-	-	-	-	76.4
Mélinite,	-	-	-	-	77.0

Moreover, the fact that the ingredients are mixed in solution insures a separation of the molecules of the same substances to a distance greater than the normal, which may be sufficient, perhaps, to account for their not exploding in the gun when used for charging shells.

Mélinite.—Mélinite, the great French explosive, was originally made by dissolving 30 parts of guncotton in 45 parts acetone

(or a mixture of ether and alcohol 2 : 1), adding 70 parts of fused and pulverized picric acid, and allowing the solvent to evaporate. Its explosion would be represented by the reaction:



Its present composition is not known. It is a yellow crystalline solid, and when used in shells about two-thirds of the space is first filled with cresilite, the remaining third being then packed with melinite.

Lyddite.—Lyddite, the great English explosive, is probably similar to the original mélinite. It is used in shells, and is considered a safe and reliable explosive. A powder fuse will not detonate it, but many metallic oxides and nitrates, when brought in contact with it at a high temperature will, and the fuse in the English service probably utilizes this principle.

11.—GUNCOTTON AND NITROTOLUENE MIXTURES.

Containing no other organic nitrate or nitro-compound.

The principle of these mixtures is that the nitrotoluene acts as a deterrent, and also so modifies the physical state of the guncotton as to enable us to regulate and control its rate of explosion.

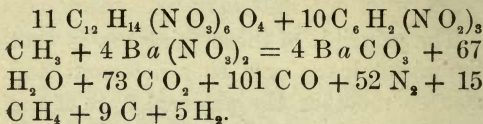
Plastomenite. — The only nitrotoluene mixture of any importance is the new smokeless powder, called Toluol Powder, or Plastomenite.

It has been greatly improved in the past two years, and as manufactured at the Güttler Factory in Reichenstein, Germany, contains, according to the analysis of Doctor Göttig, Professor at the Royal Artillery and Engineer School:

Nitrated Toluene, α -trinitrotoluene (1 : 2 : 4 : 6), $C_6H_2(NO_2)_3CH_3$, and ortho-nitrotoluene, $C_6H_4(NO_2)CH_3$	-	22.06
Nitrocellulose (partly soluble, 12.33 % nitrogen), $C_{12}H_{14}(NO_3)_6O_4$	-	67.48
Barium nitrate,	- - -	9.76

Moisture, - - - - - 0.90

The reaction for its explosion at high pressure is, according to Professor Göttig, as follows :



As regards residue and freedom from smoke the new powder meets all requirements ; the weight and volume of the charge required is still an objection, but this is more than counterbalanced by the advantageous properties of the explosive, namely, its strength, stability at high temperatures, and resistance to the action of atmospheric moisture, safety in preparation and handling, and easy inflammability in the gun.

12.—GUNCOTTON AND NITROGLYCERINE MIXTURES.

The guncotton and nitroglycerine mixtures are among the most important and energetic of the explosives.

The principles involved in their manufacture are:

1. Guncotton has a deficiency of oxygen and nitroglycerine a slight excess, so that a proper mixture would appear to be advantageous.

2. Guncotton is solid and porous, and nitroglycerine is liquid, so that a solid mass results from their mixture, which is more convenient to handle than the liquid nitroglycerine.

3. The addition of camphor, resin, and similar substances causes a change in the cohesion of the mass, increasing its solidity and elasticity, so that a much larger mass takes up the initial shock in explosion, hence there is less danger of a local sudden rise of temperature (which is essential for detonation), and the explosive is therefore less sensitive.

4. Certain substances (low explosive mixtures, etc.) moderate the force of explosion of these high explosives, and their admixture, consequently, enables us to make explosives of various grades from the same ingredients.

Explosive Gelatine.—Explosive Gelatine, or Blasting Gelatine, is composed of nitro-cotton (with not over 11 per cent. of nitrogen), carefully dried, mixed with nitro-glycerine, also carefully dried, the amount of nitro-cotton varying from 4 to 8 per cent.; after kneading, the mixture is made into cartridges by a special machine, which forces it out in the form of a long cylinder, the latter being then cut into proper lengths, and each cartridge wrapped with paraffined paper or parchment paper.

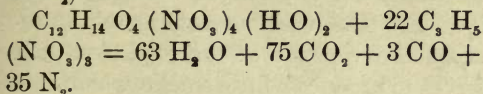
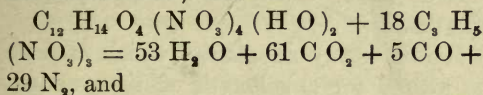
It is a yellow, translucent, elastic solid, practically unaffected by water, which when not confined burns but does not explode, but when confined explodes at about 204° C. It is less liable to freeze than dynamite, but when frozen is more sensitive.

Military Gelatine.—Military Gelatine is an explosive gelatine with a small percentage of camphor added.

There are several varieties :

	<i>Austrian.</i>	<i>Italian.</i>
Nitroglycerine, - -	90	92
Soluble guncotton, - -	10	8
Camphor (added), -	4%	5%

The reactions for explosion (assuming the tetranitrate) are:



Evidently, the oxidation in the second case is a little more complete than in the first.

Military gelatine resembles explosive gelatine in appearance and properties, but is much less sensitive.

Cordite.—Cordite, the British smokeless powder, is composed of 58 parts nitroglycerine, 37 parts guncotton and 5 parts vaseline.

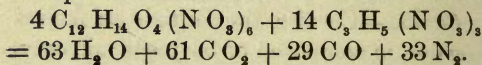
The nitroglycerine is poured over the guncotton, and the two are mixed by hand; the resulting mass, which looks like moist sugar, is placed in the kneading machines with the proper amount of acetone and incorporated; the vaseline is added and the incorporation continued; the cordite is first pressed, and is then squeezed through

dies, and issued in the form of cords of various sizes, which are cut into proper lengths.

It is a horny substance, which cannot be heated for any length of time above 100° F. The vaseline acts merely to restrain the violence of the explosion, and serves to produce a little smoke, which acts as a lubricant in the bore of the gun.

The cords burn progressively from surface to center, so that the rate of combustion can be regulated by the size of the cord.

Explosion reaction:



W.-A. Powder.—*W.-A. Powder* is one of the smokeless powders, and is made by the American Smokeless Powder Company; it consists of the highest grade of guncotton mixed with purified nitroglycerine (the latter dissolved in acetone before being added to the guncotton), to which nitrates and an organic deterrent are added; it is pressed into cords similar to cordite.

Ballistite.—*Ballistite*, or *Filite*, the Ital

ian service smokeless powder, is made by dissolving diphenylamine, $\text{N H (C}_6\text{H}_5)_2$, in nitroglycerine, and mixing the liquid with soluble guncotton (in a vessel containing hot water) by means of compressed air; then removing the water by centrifugal machines and absorbents, and passing the mixture repeatedly between heated rollers; it is either pressed into cords, or granulated in cubes.

Equal parts of guncotton and nitroglycerine are used, and about one per cent. of diphenylamine.

Maxim-Schüpphaus Powder. — Maxim-Schüpphaus smokeless powder, in one of its forms, consists of:

Mixed nitrocottons,	-	-	-	90	parts.
Nitroglycerine,	-	-	-	9	"
Urea,	-	-	-	1	"

It is made by mixing in a kneading machine at about 120° F. , 80 lbs. of insoluble guncotton (with 13.3 per cent. nitrogen), 8 lbs. of soluble guncotton (gelatin-pyroxylin, with 12 per cent. nitrogen, soluble in nitroglycerine below 180° F.), 12 lbs. nitroglycerine, 35 lbs. acetone, and 1 lb.

urea (dissolved in methyl alcohol). The mealy mass is then rolled into sheets, pressed out in the form of multi-perforated cylinders, and dried in a vacuum.

Peyton Powder.—Peyton Powder is a smokeless powder, manufactured by the California Powder Works, and consists of a gelatinized mixture of nitroglycerine (38 per cent.), and guncotton (40 per cent.), using acetone as the solvent for incorporation, with other substances added.

Forcite.—Forcite, or Gelatine Dynamite, is composed of blasting gelatine (98 parts nitroglycerine to 2 parts nitrocotton) and a low explosive base (sodium nitrate 76, sulphur 3, wood-tar 20, wood pulp 1).

Ecrasite.—Ecrasite is an explosive manufactured at the Siersch dynamite factory in Pressburg, Austria, and used in charging shells. It is composed essentially of blasting gelatine and ammonium picrate.

There are many other smokeless powders included in this section, such as the Belgian *Wetteren Powder* and the American *Leonard Powder*, but they illustrate no new principles.

III. MIXTURES.

CONTAINING NO NITRO-COMPOUNDS OR ORGANIC NITRATES.

This class of explosives, the earliest known, and the simplest from a mechanical point of view, are yet the most complex from a chemical point of view. It was very natural, in the early state of chemical knowledge, to mix together mechanically the commonest combustibles, charcoal and sulphur, with the best known solid oxidiser, nitre, to obtain the first explosive; but it required a knowledge of structural formulae to understand how to obtain the atoms of combustibles and those of oxygen ready mixed in the molecule, as in our later explosives.

In all mixtures of this class one of the ingredients is a combustible substance, and another contains the requisite oxygen for this combustion and gives it up readily.

This class comprises the following groups:

Nitrogen Oxide Group.

Nitrate Group.

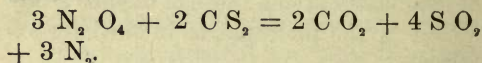
Chlorate Group.

Fulminate Group.

1.—NITROGEN OXIDE GROUP.

This, the simplest group of this class of mixtures, in which nitrogen oxide is the oxidising ingredient, comprises but one explosive of any importance.

Panclostite. — Panclostite, one of the Sprengel class of explosives, is made by mixing 3 volumes of liquid nitrogen tetroxide with 2 volumes of liquid carbon disulphide. It merely burns when ignited but may be exploded by means of a detonator.



Other proportions are used for obtaining different effects, and other combustibles may be substituted for the carbon disulphide.

2.—NITRATE GROUP.

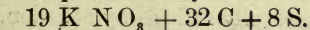
The nitrate group includes all those

mixtures in which the constituent to be oxidised is some form of carbon, and the oxidising constituent is a nitrate.

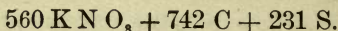
In all the nitrates used in these mixtures *five-sixths* only of the oxygen present is available for combustion.

Black Gunpowder.—Black Gunpowder, the oldest of all our explosives, probably originated in the far East, found its way to Constantinople, where it became known as *Greek fire*, and was introduced, about 1353, in Augsburg, the metropolis then of the Alemannic countries in Germany, where it was improved to the present form of gunpowder, and whence a knowledge of its composition rapidly spread over Europe.

Black gunpowder is a mixture of 75 parts of potassium nitrate, 15 parts of charcoal and 10 pounds of sulphur. Regarding the charcoal as pure carbon (which is, of course, not strictly true, since charcoal always has a considerable percentage of hydrogen and oxygen), this composition would be represented by the formula:



But, if the amount of carbon actually present in the charcoal be taken (omitting the hydrogen and oxygen), its composition is:



The purpose of the charcoal is to furnish the combustible, mainly carbon, and by oxidation to produce a gas and evolve heat; the nitre furnishes the oxygen for the oxidation of the carbon and part of the sulphur, and at the same time adds to the heat by furnishing a base (K_2O) for part of the carbon dioxide and sulphur trioxide to combine with, resulting, however, in a loss of gas; the object of adding sulphur is to lower the temperature of ignition of the mixture and to accelerate the combustion, but it also incidentally raises the temperature by combination with potassium and oxygen, and increases the volume of gas indirectly by combining with a part of the potassium, which would otherwise combine with carbon dioxide and thereby diminish the volume of gas.

For the manufacture of gunpowder the nitre is carefully refined by solution, filtra-

tion, crystallization and washing; the sulphur is purified by distillation, *distilled* sulphur, the electronegative variety, being the only kind suitable for making gunpowder; the charcoal is obtained from selected willow, alder or black dogwood by distillation at temperatures between 360° and 520° C.

The ingredients, in proper proportions, are placed in the mixing machine, where they are mixed by means of a revolving drum with fork-shaped arms over its surface; and the mixture is passed through a sieve into a hopper, and collected in bags. It is then transferred to the incorporating mill in 50 pound charges, spread evenly over the bed with a wooden rake, and about 2 pints of water are added (from time to time more water is added); the ingredients are thoroughly incorporated here by means of two cylindrical edge-runners. The mill cake thus formed is broken up by passing it in succession between two pairs of rollers, one above the other, through which it falls into boxes, and is conveyed thence to the press, where it is pressed into sheets.

These sheets are taken to the granulating machine, which has several pairs of rollers (placed obliquely one above the other), fitted with teeth of varying sizes and separated by screens; the press-cake passes through the first pair of rollers to the first screen, the finer material passing through and being sifted by the finer screens below, the coarser material passing to the next set of rollers, and so on. The different sizes of grain are thus collected separately below.

The granulated powder is next passed through the dusting reels, where it is revolved in horizontal or slightly inclined cylindrical drums of dusting cloth (18 to 56 meshes to the inch). The clean powder is then glazed (with or without the addition of a little graphite) in horizontal revolving glazing barrels, after which it is again dusted. The powder is then dried on trays or frames with canvas bottoms, placed on racks in a room kept at 120° to 145° F., and is finished by running it again in a dusting reel.

Common gunpowder is of uniform dark

gray color, and when granulated its grains are hard and angular, do not soil the fingers, and are free from dust. Its density varies from 1.50 to 1.85. When exposed to moist air it absorbs considerable moisture, which not only interferes directly with its ballistic qualities, but also causes the gunpowder to deteriorate by dissolving a portion of the nitre, the latter recrystallizing on the grains and being thus removed from intimate mixture with sulphur and charcoal. Immersion in water dissolves the nitre and destroys the powder.

Since, in all explosive mixtures which are aggregated into grains, the combustion takes place in successive layers over the surface (provided the density be sufficient to prevent the grains from being disintegrated), the rate of combustion of a given charge can be regulated by varying the size of the grain, the powders of larger grain being the slower in burning. Moreover, increase of density will also diminish rate of burning, since the heated gases which ignite the successive layers penetrate less easily. When a charge of fine

grain powder is ignited, the time of combustion from surface to center of each grain is very short, so that most of the gas is given off at once, resulting in great initial pressure; but, when coarse grain powder is ignited, a longer time is required for the combustion of each grain, and the gases are given off more gradually, resulting in a more moderate initial pressure. On this principle the various large grained powders, mammoth, hexagonal and pebble, were prepared.

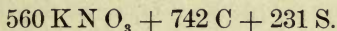
But, since the surface of the grain is gradually diminished during this combustion, the quantity of gas given off in a given time grows smaller and smaller, although (in a gun) the space in which it expands grows larger and larger as the projectile moves out, and therefore the pressure on the latter is diminishing all the time it is in the bore. Now, by perforating the powder grains with cylindrical channels, so that on ignition the grain is consumed inside and out at the same time, the surface of combustion gradually increases, hence, the volume of gases given

off increases, and therefore (without exceeding the maximum pressure at the beginning) the pressure is kept up well during the entire time the projectile is in the bore. This is the principle on which the perforated prismatic and other perforated powders are made.

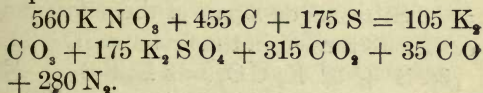
Gunpowder explodes at 316° C., and can be exploded by percussion. When mixed with high explosives it can also be detonated.

In its explosion there are two stages:

First Stage.—Military gunpowder (neglecting the hydrogen and oxygen of the charcoal) may be represented by the formula :



The first stage in its explosion is thus represented:



In this first stage all the nitre, part of the carbon and part of the sulphur react, producing, besides the gases, potassium sulphate and potassium carbonate. The

relative amounts of heat produced by the formation of the potassium carbonate, the potassium sulphate, and the carbon dioxide present, respectively, are 1 : 2 : 1. All the oxygen of the charcoal and part of the hydrogen are given off in the form of water; the rest of the hydrogen is given off free, or unites with carbon, sulphur and nitrogen, respectively, producing marsh gas, sulphuretted hydrogen, and ammonia, but these secondary products do not amount to 2 per cent. of the total products.

Second Stage.—The remainder of the carbon of the gunpowder ($742 - 455 = 287 \text{ C}$) reacts on a part of the potassium sulphate formed in the first stage:

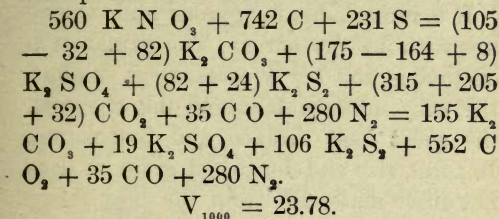
$287 \text{ C} + 164 \text{ K}_2 \text{ S O}_4 = 82 \text{ K}_2 \text{ C O}_3 + 82 \text{ K}_2 \text{ S}_2 + 205 \text{ C O}_2$; and the remainder of the sulphur of the powder ($231 - 175 = 56 \text{ S}$) reacts on a part of the potassium carbonate formed in the first stage:

$56 \text{ S} + 32 \text{ K}_2 \text{ C O}_3 = 8 \text{ K}_2 \text{ S O}_4 + 24 \text{ K}_2 \text{ S}_2 + 32 \text{ C O}_2$.

In this second stage the volume of gas formed during the first stage is increased, but the temperature is lowered, because

heat is absorbed. A portion of the carbon monoxide in the products is formed during this stage by the action of free carbon or potassium disulphide on carbon dioxide.

The following reaction shows the relation between the original powder and the final products:



Brown Powder.—Brown or Cocoa Powder is composed of 79 parts of nitre, 18 parts of charcoal and 3 parts of sulphur. The charcoal is prepared from straw carbonized in a special manner, so that its composition by analysis differs considerably from that used in black gunpowder:

Charcoal for

	<i>Brown Powder.</i>		<i>Black Powder.</i>
	Professor Munroe.		Professor Bloxam.
Carbon -	48.33	-	85.80
Hydrogen -	5.57	-	3.13
Oxygen -	44.77	-	9.47
Ash -	1.33	-	1.60

The finished powder is in hexagonal prisms perforated axially.

It is remarkable for giving high velocities with low pressures. The explanation of this is the low percentage of sulphur, the easy inflammability of the charcoal, the great heat evolved, and dissociation. In form, size and density of grain it does not differ materially from the best forms of black powder. The low percentage of sulphur raises its igniting point (as compared with black powder), so that the action is comparatively slow at first, each particle requiring a slightly higher temperature for ignition than in case of black powder; when the temperature, however, reaches a certain point, and the powder begins to burn well, the easy inflammability of the charcoal comes into play (especially as the grains become broken up),

and gas is given off more rapidly than in case of black powder, but by this time it has also more space to expand into, so that the pressure on the walls of the gun is not too great; the greater heat evolved (which comes into play about the same time that the rapid combustion does, of course) expands the gases more and so tends to give greater pressure when the latter is most needed, *i. e.*, as the projectile moves along the bore and the space behind it becomes greater; finally, underburnt charcoal (and therefore the powder made from it) contains carbohydrates, and these are known to undergo dissociation very readily, so that as the temperature rises decomposition goes on, with liberation of gas, until the pressure reaches a certain point for the then temperature, when it will cease; now, if the pressure goes on increasing, due to the continued rapid liberation of gases, while the temperature does not increase sufficiently to prevent it, recombination will take place, with diminution of gaseous matter, thus preventing a too rapid rise of pressure; as the temperature continues

to rise, however, decomposition again commences and continues until the pressure of the liberated gas reaches another point (corresponding to this higher temperature), when it will again cease, and so on. Dissociation, therefore, acts like an automatic pressure regulator: when the pressure tends to get great recombination begins diminishing the gases, and preventing a great increase of pressure; when the pressure tends to fall decomposition goes on, increasing the gases, and thus increasing the pressure again.

The dissociation of water vapor into hydrogen and oxygen probably plays no part whatever in these reactions, since there are so many other substances present that are decomposed so much more easily than this very stable and strong compound, and whose action would come into play long before the water vapor could possibly be affected; moreover, these more easily decomposable substances (carbohydrates, etc.) require no assumptions (as does the dissociation of water vapor) as to the actual temperature of the gases in the bore of the

gun, or the dissociation temperature of water vapor under the pressure existing, both of which are still matters of more or less doubt.

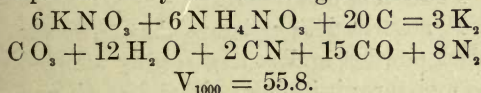
Du Pont Brown Powder.—Du Pont Brown Powder is composed of:

Nitre,	-	-	-	-	78 parts.
Sulphur,	-	-	-	-	3 “
Carbohydrates,	-	-	-	-	4 “
Baked Wood,	-	-	-	-	12 “

In this powder the charcoal is specially prepared so as to have the proper chemical composition and the proper physical texture, and carbohydrates are specially added. The explanation of the action of this powder is exactly the same as in case of ordinary brown powder.

Amide Powder.—Amide powder consists of potassium nitrate (101 parts) ammonium nitrate (80 parts) and charcoal (40 parts).

Its composition and explosion may be represented by the following reaction:



Powders containing ammonium nitrate

are usually safer for use in coal mines than ordinary powder or the usual high explosives, as they do not fire the mine so readily, but some of the more recent mixtures containing high explosives are found in practice to be much more reliable.

Westphalite. — Westphalite, a blasting powder used in coal mines, is composed of ammonium nitrate (91 parts), nitre (41 parts) and resin (5 parts).

Cologne-Rottweiler Safety Powder. — Cologne-Rottweiler Safety Powder, another blasting powder, contains ammonium nitrate (92.3 parts), barium nitrate (0.3 parts) and oil of sulphur (6.4 parts).

Petroclastite. — Petroclastite or Haloclastite, is composed of :

Sodium nitrate	-	-	-	69 parts.
Potassium nitrate	-	-	-	5 “
Sulphur	-	-	-	10 “
Coal tar	-	-	-	15 “
Potassium bichromate	-	-	-	1 “

It absorbs less moisture than ordinary black powder, and is less readily affected by moisture; it ignites only at 350° C., and burns with a quiet flame without sparks;

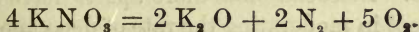
its gases are not so injurious to breathe, and the smoke rapidly settles; it can be detonated by an ordinary fuse, and its force of explosion is somewhat greater than that of ordinary gunpowder.

It is particularly useful in mining soft material like rock-salt.

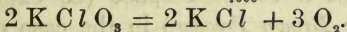
There are many other mixtures of this kind used in blasting, but they illustrate no new principles.

3.—THE CHLORATE GROUP.

The chlorate group includes all those mixtures in which the constituent to be oxidised is some form of carbon, and the oxidising constituent is a chlorate. In the chlorates used in these mixtures *all* the oxygen is available for combustion, nevertheless, weight for weight, potassium nitrate gives more available oxygen than potassium chlorate :



$$404.4 : 160 :: 1000 : V_{1000} = 39.56.$$



$$245.2 : 96 :: 1000 : V'_{1000} = 39.15.$$

Chlorate powders are all liable to be exploded by friction or percussion, and even spontaneously, especially when long kept.

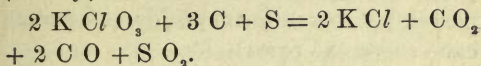
Chlorate powders, of composition exactly similar to nitrate powders, are more energetic than the latter for three reasons:

1. The atoms of potassium chlorate are held together by so feeble an attraction that when the molecule decomposes (as above) the heat of combination in forming KCl and O_2 is greater than the loss of heat due to the decomposition of the original molecule, so that in the chlorates heat is evolved, whereas in the nitrates heat is absorbed, in this part of the process of explosion; this heat adds its effects, of course, to the heat of explosion proper.

2. The greater instability of the chlorates (in presence of oxidisable substances) causes greater rapidity in the chemical reactions.

3. Dissociation is more apt to have an effect in moderating the rate of decomposition in a confined space (as explained under *Brown Powder*) in the case of the nitrate powders, where more complex

(ternary) compounds, such as potassium sulphate and potassium carbonate, are produced, than in the case of the chlorate powders (made just like the nitrate powders), where the products are all simpler (binary) and more stable compounds:



No chlorate powder of composition similar to ordinary gunpowder is in use as a powder. In all the mixtures used or proposed the sensitiveness is reduced by various expedients: either by replacing part of the chlorate by a nitrate (or other less energetic oxidiser), or by adding complex compounds so as to dilute the chlorate and at the same time have the moderating advantages of dissociation.

In fuse compositions and priming powders, of course, the suddenness of the explosion is not only not an objection, but is in fact the very quality desired.

Aside from fuse compositions and priming materials, there are but two chlorate powders of any interest or importance.

Asphaline.—Asphaline is composed of

potassium chlorate (54 parts), bran (42 parts), potassium nitrate and potassium sulphate (4 parts).

White Powder.—White powder, German powder, American powder, or Augendre's powder, consists of potassium chlorate (50 parts), potassium ferrocyanide (25 parts), cane sugar (25 parts).

This mixture (besides being an explosive in the ordinary sense) can be readily exploded by contact with strong sulphuric acid.

Harvey Fuse Composition.—Harvey fuse composition consists of a mixture of potassium chlorate (17.0 parts), cane sugar (4.5 parts) and nut-galls (1.5 parts). It is ignited by means of sulphuric acid.

U. S. Naval Friction Fuse Composition.—U. S. Naval friction fuse composition is made by pulverizing and mixing, under alcohol, potassium chlorate (45 parts), antimony sulphide (20.75 parts), amorphous phosphorus (5.75 parts) and carbon (28.50 parts). It is used (while wet) for exploding torpedoes by frictional electricity.

English Priming Material.—English prim-

ing material consists of copper subsulphide, copper subphosphide, and potassium chlorate in various proportions, the ingredients being mixed under alcohol.

Austrian Priming Material. — Austrian priming material is composed of equal parts of potassium chlorate and antimony sulphide, with a trace of plumbago.

4.—FULMINATE GROUP.

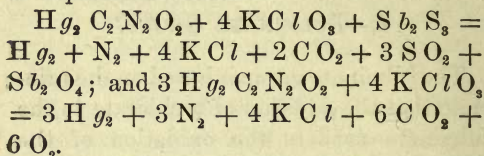
The fulminate group is based on the principle that the addition of a chlorate to the fulminate renders the oxidation of the carbon more complete, and at the same time the addition of some inert solid serves to regulate its action somewhat; or on the fact that sulphur has a low igniting point and burns with great energy and a flame not readily extinguished, qualities which make it useful for insuring the communication of flame.

The mixtures of this group are used mainly in cap and fuse compositions and in detonators.

Cap Composition. — Cap composition con-

sists, for gunpowder caps, of 37.5 parts mercury fulminate, 37.5 parts potassium chlorate and 25 parts antimony sulphide; for blasting caps, of 75 parts mercury fulminate and 25 parts potassium chlorate. A little ground glass is usually added, as well as a solution of gum.

The explosion of these compositions may be represented thus :



Electric Fuse Composition.—The fuses to be fired by electricity contain at one end a mixture similar to cap composition, at the other a mixture of sulphur and ground glass, with a thin layer of guncotton between, surrounding the wire whose fusion is to ignite the fuse.

Detonators.—Detonators contain mercury fulminate in one end, a mixture of sulphur and ground glass in the other, with a layer of guncotton between.

Single detonators contain three grains of

mercury fulminate, and others are rated as *double*, *treble*, etc., according to the weight of fulminate (compared with single ones) which they contain.

RECENT IMPROVEMENTS IN SMOKE- LESS POWDERS.

There are two kinds of smokeless powder in use by the world's armies and navies to-day :

1. Pure nitrocellulose powders.
2. Nitrocellulose powders, containing also nitroglycerine, usually referred to as "Nitroglycerine powders."

The former are gradually gaining ground over the latter, principally because of the more rapid erosion of the rifling of musket and cannon bores due to the nitroglycerine.

The improvements in smokeless powders have been very great in recent years, but each nation endeavors to keep the special processes of manufacture employed as secret as possible.

Some of the main features in these improvements can be outlined, however.

By simply reducing the weight of the small-arm projectile it was found that no considerable increase in muzzle velocity took place (with the older form of powder),

and an increase in the charge gave too high pressures.

Consequently a powder more *progressive* in its action was required. This has been obtained partly by making a *denser* material and partly by giving it a more favorable *form*, the combustion being regulated so that the pressure of the gases, after reaching its maximum, remains practically constant.

The muzzle velocity has thus been greatly increased, without raising the pressure very much, and yet the space occupied by the charge is the same as in the older cartridge. A denser and finer-grained powder has permitted of increasing the *weight* of the charge without increasing its volume, and the more progressive combustion of the powder keeps the pressure down, and yet gives greater muzzle velocity, because the full pressure once attained acts till the projectile leaves the bore.

The *processes* of making nitrocellulose powders have also been greatly improved of late years.

The Cologne-Rottweil Powder Works, for example, wash the guncotton in closed kettles with steam under a pressure of three to five atmospheres, at 135° to 150°C . This reduces the amount of water required so much that only from $\frac{1}{20}$ to $\frac{1}{50}$ of that used in the old process is needed, and much time is saved, as only from two to five hours are required. The result is purer guncotton than that which had been washed for 100 hours by the older process.

Moreover, the fibers of the guncotton are thereby changed to a fine dust, which is better for the subsequent treatment.

The solvent used to gelatinize the powdered nitrocellulose has been acetic ether or acetone until quite recently. Now, ether-alcohol (a mixture of sulphuric ether and ethyl alcohol) is very generally used.

The powder, after gelatinization, is pressed through kneading machines into cords of various thickness, from thin threads to tubes of half an inch or more in diameter. The finer threads are solid and are used as such in small-caliber fire-arms.

The tubes for larger caliber guns are hollow (like macaroni), so that combustion takes place at the same time on the inner surface as well as the outer.

To make the Leaflet Powder the gelatine mass is pressed into sheets, cut into strips, and the strips chopped off into small flat leaflets, those of the German army powder, for example, having the following dimensions:

Side of square surface.	0.06 in.
Thickness	0.008 in.

The finer cannon powder:

Side of square surface	0.1 in.
Thickness	0.016–0.020 in.

The coarser cannon powder:

Side of square surface	0.2 in.
Thickness	0.028 in.

The powders in use by the principal nations of the world are as follows :

GERMANY.

The German army uses pure nitrocellulose powder almost entirely, while the navy

uses nitroglycerine powder in all its guns except the 8 mm. machine guns.

FRANCE.

The French use exclusively nitrocellulose powders, designated as B (Boulenger) Powders, the latest being B N (Boulenger nouvelle), gelatinized by means of ether-alcohol, and B M (Boulenger marine), the powder for the navy.

Other forms are: B G C (for coast guns), B S P (for siege and fortification guns), B C (for field guns) and B F (for muskets).

ITALY.

In Italy, *Ballistite* is still used, in various forms. It is prepared, however, by adding from 0.5 to 1.0 per cent of aniline (instead of diphenylamine) to a mixture of equal parts of guncotton and nitroglycerine. It is in granular form.

The field guns use it in the form of long threads (hence called *Filite*), varying in diameter for different calibers from 0.01 to 0.02 inch in diameter.

In 1896 *Solenite*, consisting of about 66

per cent. guncotton, 33 per cent. nitroglycerine and 1.1 per cent. vaseline, was definitely adopted for the infantry rifle and provisionally for field guns.

ENGLAND.

The form and composition of the English Cordite have been considerably changed.

The new powder is called Cordite M D (modified cordite), and is similar to the original cordite, but the percentage of nitrocellulose (or guncotton) has been raised to 65 per cent., while that of the nitroglycerine has been reduced to 30 per cent.

More acetone is also used in gelatinizing.

This new form has less effect on the rifling, and fire-arms last longer in consequence.

For small arms it is made in the form of long thin strips, which are bundled together for the charge of a musket, the strips being the full length of the charge.

AUSTRO-HUNGARY.

In Austro-Hungary a pure nitrocellulose powder is used, in various forms:

For muskets, in the form of very small discs; for field guns in cylinders, for siege guns in square leaflets, for rapid-fire guns in strips, and for guns of heavy caliber in the form of hollow tubes.

RUSSIA.

Russia uses the pyrocollodion powder both in the navy and the army, and generally in the form of leaflets or flat squares of various sizes and thickness.

These are the principal powders in use by the world's armies and navies at the present time, but changes are very rapid nowadays and all nations are striving to surpass one another in the ballistic qualities of their fire-arms, hence also in their powders.

Improvements are being constantly made, but as the processes are kept secret, they are slow to become generally known to the world at large.

INDEX.

	Page
Abel's Powder, ...	95
Aetna Powder, ...	105
Alcohols, ...	64
Alcohol Series, ...	65
Alcohol Series, Derivatives of	64
Alcohols, Hexatomic, Derivatives of	72
" Triatomic, Derivatives of.	65
American Powder, ...	142
American Safety Powder, ...	105
Amide Powder, ...	137
Ammonites, ...	96
Ammonium Hydrazoate, ...	42
Ammonium Picrate, ...	57
Ardeer Powder, Nobel	102
<i>Arms and Explosives,</i>	V, VI
Aromatic Series, Derivatives of	49, 62
Asphaline, ...	141
Atlas Powder, ...	28, 105
Atlas A Powder, ...	103
Augendre's Powder, ...	142
Austrian Priming Material, ...	143
Azo-benzene, ...	43
Azo-compounds, ...	42
Ballistite, ...	120
Bellite, ...	28, 91

Benzene, ...	50
Benzene, Derivatives of	51
Benzene Series, ...	49
Benzene Series, Derivatives of	49, 51, 62
Berthelot, ...	III
B N, Poudre	110
Borlinetto's Powder, ...	95
B, Poudre	107
Bromamide, ...	40
Brown Powder, Common	28, 133
" Du Pont	28, 137
Bruff, Captain L. L.	VI
Bruguère's Powder, ...	95
Cap Composition, ...	143
Carbodynamite, ...	102
Carbolic Acid, ...	54
Carbonite, ...	103
Castellanos Powder, ...	105, 106
Cellulose, ...	72
Chemical Action in Explosive Compounds, ...	3
" " " Mixtures, ...	3
" Composition of Explosives, ...	6
<i>Chemistry and Explosives, Lectures on,</i> Munroe	IV, V
<i>Chemistry, Descriptive General, Tillman</i>	IV, V
" <i>The New, Cooke,</i>	V
Chloramide, ...	38
Chlorate Group of Explosive Mixtures, ...	139
Classes of Explosive Materials, ...	2
Collodion Guncotton, ...	75

Cologne-Rottweiler Safety Powder, .	138
Composition, Cap	143
" Fuse	142
" Priming	142, 143
Compounds, ...	36
Cooke, Prof. J. P. . . .	IV, V
Copper Amine, ...	41
" Fulminate, ...	47
Cordite, ...	119
Cotton Powder, No. 1	108
" No. 2	109
" No. 3	112
Cresol, ...	58
Critical Velocity of Initial Decomposition, .	19
Cundill, Lieutenant-Colonel J. P. . . .	V
Deflagration, ...	15
Derivatives of Benzene, ...	51
" Naphthalene, ...	59
" Hexatomic Alcohols, ...	72
" the Alcohol Series, ...	64
" the Benzene Series, ...	49, 62
" the Naphthalene Series, ...	59
" Toluene, ...	57
" Triatomic Alcohols, ...	65
<i>Descriptive General Chemistry, Tillman</i>	V
Designolle's Powder, ...	95
Detonation by Shock, ...	18
" by Influence, ...	19
Detonators, ...	18, 144
Diazobenzene Nitrate, ...	62

	Page.
<i>Dictionary of Explosives</i> , Cundill . . .	V, VI
Dinitrobenzene, ...	53
Dinitronapthalene, ...	60
Dinitrotoluene	58
Dissociation, ...	33, 135, 140
Dualin, ...	103
Du Pont Brown Powder, ...	28, 137
Dynamite, No. 1	28, 99
" No. 2	102
Dynamites, ...	97
 Ecrasite, ...	 58, 122
Efficiencies of Powders Compared, ...	28, 29, 34
Electric Fuse Composition, ...	144
Emmensite, ...	28, 95
English Priming Material, ...	142
Explosion by Influence, ...	19
Explosions, Orders of	18
Explosion, The Force of	23
" The Phenomena of	4
" The Products of	21
Explosive, An	1
Explosive Compounds, Groups of	36
Explosive Gelatine, ...	28, 118
Explosive Materials, ...	1
Explosive Materials, Classes of	2
Explosives, ...	2
Explosives, Chemical Composition of	6
<i>Explosives</i> , <i>Dictionary of</i> , Cundill	V, VI
Explosive, Sevrans Livry	108
Explosives, High	4

Explosives, Low	4
<i>Explosives, Lectures on Chemistry and,</i>	
Munroe	IV, V
<i>Explosives, Lectures on, Walke</i>	IV, V
Favier Powders, ...	96
Filite, ...	120
Flameless Securite, ...	92
Fluoramide, ...	40
Fontaine's Powder, ...	95
Force of Explosion, ...	23
Forcite, ...	122
Friction Fuse Composition, U. S. Naval	142
Fulminate Group of Explosive Mixtures, ...	143
Fulminate, Copper	47
" Gold	47
" Mercury	28, 46
" Platinum	47
" Silver	46
" Silver Ammonium	47
" Silver Potassium	47
" Zinc	47
Fulminates, ...	45
Fuse Composition, Electric	144
" Harvey	142
" U. S. Naval Friction	142
Gelatine Dynamite, ...	122
Gelatine, Explosive	28, 118
" Military	118
German Powder, ...	142

	Page.
Giant Powder, No. 1	101
Giant Powder, No. 2	103
Glucose, ...	72
Glycerine, ...	65
Gold Fulminate, ...	47
Griess, P.	43
Grisoutine, ...	101
Grisoutine Roche, ...	97
Guncotton, ...	28, 79
Guncotton and Azo-compound Mixtures, ...	111
" " Nitrobenzene Mixtures, ...	111
" " Nitroglycerine Mixtures, ...	116
" " Nitrotoluene Mixtures, ...	115
" " Picrate Mixtures, ...	113
Guncotton Mixtures, ...	106
Gunpowder, Black	28, 125
" Brown	133
" Du Pont Brown	137
Haloclastite, ...	138
Harvey Fuse Composition, ...	142
Hecla Powder, ...	105
Hellhoffite, ...	28, 31, 93
Hercules Powder, ...	104
Hexatomic Alcohols, Derivatives of	72
High Explosives, ...	4
Horsley Powder, ...	105
Hydrazoic Acid, ...	41
Indurite, ...	112
Iodoamide, ...	39

	Page.
Judson Powder, ...	105
Kohlencarbonit, ...	103
Lactose, ...	73
Leonard Powder, ...	122
Low Explosives, ...	4
Lyddite, ...	114
Mannite, ...	72
Material, Priming, Austrian	143
“ English	142
Maxim-Schüpphaus Powder, ...	107, 121
Mélinite, ...	28, 113
Mendeléef, Professor	28, 34
Mercury Amine, ...	41
Mercury Fulminate. . . .	28, 46
Meta-amidodiazobenzolimide, ...	44
<i>Meta</i> -compounds, ...	50
Meta-ditriazobenzoic Acid, ...	44
Metamidotriazobenzoic Acid, ...	44
<i>Militaer Wochenblatt</i> , ...	VI
Military Gelatine, ...	118
Mixtures, Chlorate Group	139
“ Containing Nitro-compounds or Organic Nitrates, ...	87
“ Containing no Nitro-compounds or Organic Nitrates	123
“ Fulminate Group	143
“ Guncotton	106
“ Guncotton and Azo-compound	111

	Page.
Mixtures, Guncotton and Nitrobenzene .	111
“ “ Nitroglycerine .	116
“ “ Nitrotoluene .	115
“ “ Picrate .	113
“ Nitrate Group . . .	124
“ Nitrobenzene . . .	91
“ Nitrogen Oxide Group . .	124
“ Nitroglycerine . . .	97
“ Nitroglycerine and Nitrobenzene .	105
“ “ Picrate .	106
“ Nitronaphthalene, . . .	96
“ Picrate	94
Mononitrobenzene, ...	51
Mononitronaphthalene, . . .	60
Mononitrotoluene, ...	57
Mortar Powder, ...	28
Munroe, Prof. C. E.	IV, V
Naphthalene, ...	59
Naphthalene, Derivatives of . .	59
Naphthalene Series, Derivatives of .	59
<i>Naval Institute, Proceedings of</i> . .	V, VI
Naval, U. S., Friction Fuse Composition .	142
“ “ Smokeless Powder . . .	109
Nitramites, ...	96
Nitrate Group of Explosive Compounds, .	124
Nitrates, Organic	61
Nitrides, ...	37
Nitrobenzene Mixtures, ...	91
Nitrobenzene Mixtures, Guncotton and .	111
Nitrobenzenes, ...	51

Nitrocellulose, ...	74
Nitrocresol, ...	58
Nitro-compounds, ...	47
Nitrocotton, Soluble	75
Nitrogen Bromide, ...	40
" Chloride, ...	38
" Fluoride, ...	40
" Iodide, ...	39
" Oxide Group of Explosive Mixtures, ...	124
" Sulphide, ...	40
Nitroglycerine, ...	28, 65
Nitroglycerine and Nitrobenzene Mixtures, ...	105
" Picrate Mixtures, ...	106
Nitroglycerine Mixtures, ...	97
Nitroglycerine Mixtures, Guncotton and	116
Nitrohydric Acid, ...	41
Nitrohydrocellulose, ...	87
Nitromannite, ...	73
Nitronaphthalene	8, 61
Nitronaphthalene Mixtures, ...	96
Nitro Starch, ...	73
Nitrosubstitution Compounds, ...	48
Nitrotoluene, ...	58
Nitrotoluene Mixtures, Guncotton and	115
Nobel Ardeer Powder, ...	102
Normal Powder, Swiss	107
Orders of Explosion, ...	18
<i>Ordnance and Gunnery</i> , Bruff	VI
Organic Nitrates, ...	61
Origin of the Reactions in Explosion, ...	12

<i>Ortho</i> Compounds, ...	50
Oxonite, ...	31, 94
Panclastite, ...	31, 124
Para-amidodiazobenzoic Acid, ...	44
<i>Para</i> Compounds, ...	50
Para-ditriazobenzene, ...	44
Petroclastite, ...	138
Peyton Powder, ...	122
Phenol, ...	54
Phenomena of Explosion, ...	4
Picrate Mixtures, ...	94
" Guncotton and	113
" Nitroglycerine and	106
Picrates, ...	54
Picric Acid, ...	54
Plastomenite, ...	115
Platinum Fulminate, ...	42
Potassium Picrate, ...	57
Potentite, ...	108
Poudre B, ...	107
Poudre B N, ...	110
Powder, Abel's	95
" Aetna	105
" American	142
" American Safety	105
" Amide	137
" Ardeer (Nobel)	102
" Atlas	28, 105
" Atlas A	103
" Augendre's	142
" R	107

Powder, B N	.	.	.	.	110
" Black	.	.	.	28,	125
" Borlinetto's	.	.	.	.	95
" Brown, Common	.	.	.	28,	133
" " Du Pont	.	.	.	28,	137
" Bruguère's	.	.	.	.	95
" Castellanos	.	.	.	105,	106
" Cologne-Rottweiler Safety	.	.	.	.	138
" Cotton No. 1	.	.	.	.	108
" " 2	.	.	.	.	109
" " 3	.	.	.	.	112
" Designolle's	.	.	.	.	95
" Du Pont Brown Powder	.	.	.	28,	137
" Favier	.	.	.	.	96
" Fontaine's	.	.	.	.	95
" German	.	.	.	.	142
" Giant No. 1,	.	.	.	.	101
" " 2,	.	.	.	.	103
" Hecla	.	.	.	.	105
" Hercules	.	.	.	.	104
" Horsley	.	.	.	.	105
" Judson	.	.	.	.	105
" Leonard	.	.	.	.	122
" Maxim-Schüpphaus	.	.	.	.	107
" Mortar	.	.	.	.	28
" Naval Smokeless (U. S.)	.	.	.	.	109
" Nobel Ardeer	.	.	.	.	102
" Normal (Swiss)	.	.	.	.	107
" Peyton	.	.	.	.	122
" Safety	.	.	.	89, 97, 101, 104,	138
" Safety (Cologne-Rottweiler)	.	.	.	.	138

Powder, Schultze	40
“ Smokeless	31
“ Swiss Normal	107
“ Toluol	115
“ Troisdorf	109
“ U. S. Naval Smokeless	109
“ Vielle’s	107
“ Volney	96
“ Vulcan	103
“ W.-A.	120
“ Wetteren	122
“ White	142
Powders, Efficiencies of, Compared	28, 29, 34
“ Strong and Rapid	25
“ Strong and Slow	26
Priming Material, Austrian	143
“ English	142
<i>Proceedings U. S. Naval Institute</i> , ...	V, VI
Products of Explosion, ...	21
Propagations of the Reactions in Explosion, ...	16
Pyrocollodion, ...	29, 76
Quinan Pressure-gauge, ...	28
Rack-a-Rock, ...	28, 31, 92
Rapidity of Reactions in Explosion, ...	14
Reactions, Origin of the	12
“ Propagation of the	16
“ Rapidity of the	14
Rendrock, ...	105
<i>Revue d’ Artillerie</i> , ...	VI

INDEX.

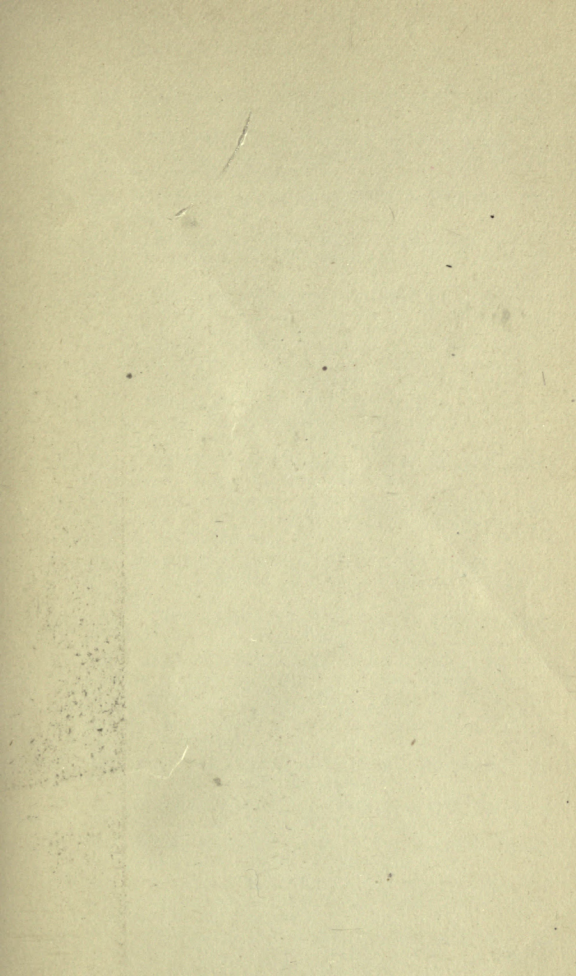
13

Page.

Rifleite, ...	111
Roburite, ...	94
Romite, ...	31
Saccharose, ...	73
Safety Powder, ... 89, 97, 101, 104, 138	
" Cologne-Rottweiler	138
Schultze Powder, ...	40
Securite, ...	92
Sensitiveness of an Explosive, ...	20
Sevrans Livry Explosive, ...	108
Silver Amine, ...	41
Silver-ammonium Fulminate, ...	47
Silver Fulminate, ...	46
Silver Hydrazoate, ...	42
Silver Nitride, ...	41
Silver-potassium Fulminate, ...	47
Smokeless Powder, ...	31
" Ballistite	120
" Cordite	119
" Filite	120
" Indurite.	112
" Leonard.	122
" Maxim-Schüpphaus	107, 121
" Peyton	122
" Plastomenite	115
" Poudre B	107
" Poudre B N	110
" Pyrocollodion	29, 76
" Rifleite	111
" Schultze	40

Smokeless Powder, Swiss Normal . . .	107
" Troisdorf . . .	109
" U. S. Naval . . .	109
" W.-A.	120
" Wetteren . . .	122
Soluble Nitrocotton, ...	75
Spontaneous Decomposition Causing Explosion, 15	
Sprengel Class of Explosives, ...	29
" " Rack-a-Rock 28, 31, 92	
" " Hellhoffite 28, 31, 93	
" " Oxonite . 31, 94	
" " Panclastite 31, 124	
" " Romite . . . 31	
Starch, ...	72
Stonite, ...	105
Strength of Explosives, ...	28
Sulphur Nitride, ...	41
Swiss Normal Powder, ...	107
Synchronous Vibrations in Explosion by In-	
fluence, ...	13
Tetranitronaphthalene, ...	61
Tillman, S. E., Professor	IV
Toluene, ...	57
Toluene, Derivatives of	57
Toluol Powder, ...	115
Tonite, ...	28, 108
Triatomic Alcohols, Derivatives of	65
Triazo-Azobenzene, ...	44
Trinitrobenzene, ...	54
Trinitrocresol, ...	58

INDEX.				15
				Page.
Trinitronaphthalene,	.	.	.	61
Trinitrotoluene,	.	.	.	58
Troisdorf Powder,	.	.	.	109
U. S. Naval Friction Fuse Composition,	.			142
" Smokeless Powder,	.	.	.	109
Vielle's Powder,	.	.	.	107
Vigorite,	.	.	.	104
Volney Powders,	.	.	.	96
Vortex Motion in Explosion by Influence,	.			13
Vulcan Powder,	.	.	.	103
Walke, Lieut. W.	.	.	.	IV, V
W.-A. Powder,	.	.	.	120
Westphalite, .	.	.	.	138
Wetterdynamite,	.	.	.	101
Wetteren Powder,	.	.	.	122
White Powder,	.	.	.	142
Xyloidine, .	.	.	.	74



- No. 47. LINKAGES: THE DIFFERENT FORMS** and Uses of Articulated Links. By J. D. C. De Roos.
- No. 48. THEORY OF SOLID AND BRACED** Elastic Arches. By William Cain, C.E. Second edition, revised and enlarged.
- No. 49. MOTION OF A SOLID IN A FLUID.** By Thomas Craig, Ph.D.
- No. 50. DWELLING-HOUSES; THEIR SANI-**tary Construction and Arrangements. By Prof. W. H. Corfield.
- No. 51. THE TELESCOPE: OPTICAL PRINCI-**ples Involved in the Construction of Refracting and Reflecting Telescopes, with a new chapter on the Evolution of the Modern Telescope, and a Bibliography to date. With diagrams and folding plates. By Thomas Nolan. Second edition, revised and enlarged.
- No. 52. IMAGINARY QUANTITIES; THEIR** Geometrical Interpretation. Translated from the French of M. Argand by Prof. A. S. Hardy.
- No. 53. INDUCTION COILS; HOW MADE AND** How Used. Eleventh American edition.
- No. 54. KINEMATICS OF MACHINERY.** By Prof. Alex. B. W. Kennedy. With an Introduction by Prof. R. H. Thurston.
- No. 55. SEWER GASES; THEIR NATURE AND** Origin. By A. de Varona. Second edition, revised and enlarged.
- *No. 56. THE ACTUAL LATERAL PRESSURE** of Earthwork. By Benj. Baker, M. Inst., C.E.
- No. 57. INCANDESCENT ELECTRIC LIGHT-**ing. A Practical Description of the Edison System. By L. H. Latimer. To which is added the Design and Operation of the Incandescent Stations, by C. J. Field; and the Maximum Efficiency of Incandescent Lamps, by John W. Howell.
- No. 58. VENTILATION OF COAL MINES.** By W. Fairley, M.E., and Geo. J. André.
- No. 59. RAILROAD ECONOMICS; OR, NOTES** With Comments. By S. W. Robinson, C.E.
- No. 60. STRENGTH OF WROUGHT-IRON** Bridge Members. By S. W. Robinson, C.E.
- No. 61. POTABLE WATER, AND METHODS OF** Detecting Impurities. By M. N. Baker. Second edition, revised and enlarged.
- No. 62. THEORY OF THE GAS-ENGINE.** By Dougald Clerk. Third edition. With additional matter. Edited by F. E. Idell, M.E.

- No. 63. HOUSE-DRAINAGE AND SANITARY** Plumbing. By W. P. Gerhard. Twelfth edition.
- No. 64. ELECTROMAGNETS.** By A. N. Mansfield. Second edition, revised.
- No. 65. POCKET LOGARITHMS TO FOUR** Places of Decimals. Including Logarithms of Numbers, etc.
- No. 66. DYNAMO-ELECTRIC MACHINERY.** By S. P. Thompson. With an Introduction by F. L. Pope. Third edition, revised.
- No. 67. HYDRAULIC TABLES FOR THE CAL-** culation of the Discharge through Sewers, Pipes, and Conduits. Based on "Kutter's Formula." By P. J. Flynn.
- No. 68. STEAM-HEATING.** By Robert Briggs. Third edition, revised, with additions by A. R. Wolff.
- No. 69. CHEMICAL PROBLEMS.** By Prof. J. C. Foye. Fifth edition, revised and enlarged.
- No. 70. EXPLOSIVE MATERIALS.** By Lieut. John P. Wisser.
- No. 71. DYNAMIC ELECTRICITY.** By John Hopkinson, J. N. Shoolbred, and R. E. Day.
- No. 72. TOPOGRAPHICAL SURVEYING.** By George J. Specht, Prof. A. S. Hardy, John B. McMaster, and H. F. Walling. Fourth edition, revised.
- No. 73. SYMBOLIC ALGEBRA; OR, THE ALGE-** bra of Algebraic Numbers. By Prof. William Cain.
- No. 74. TESTING MACHINES; THEIR HIS-** tory, Construction and Use. By Arthur V. Abbott.
- No. 75. RECENT PROGRESS IN DYNAMO-** electric Machines. Being a Supplement to "Dynamo-electric Machinery." By Prof. Sylvanus P. Thompson.
- No. 76. MODERN REPRODUCTIVE GRAPHIC** Processes. By Lieut. James S. Pettit, U.S.A.
- No. 77. STADIA SURVEYING.** The Theory of Stadia Measurements. By Arthur Winslow. Eighth edition.
- No. 78. THE STEAM-ENGINE INDICATOR** and Its Use. By W. B. Le Van.
- No. 79. THE FIGURE OF THE EARTH.** By Frank C. Roberts, C.E.
- No. 80. HEALTHY FOUNDATIONS FOR** Houses. By Glenn Brown.
- *No. 81. WATER METERS: COMPARATIVE** Tests of Accuracy, Delivery, etc. Distinctive Features of the Worthington, Kennedy, Siemens, and Hesse meters. By Ross E. Browne.

- No. 82. THE PRESERVATION OF TIMBER BY** the Use of Antiseptics. By Samuel Bagster Boulton, C.E.
- No. 83. MECHANICAL INTEGRATORS.** By Prof. Henry S. H. Shaw, C.E.
- No. 84. FLOW OF WATER IN OPEN CHAN-** nels, Pipes, Conduits, Sewers, etc. With Tables. By P. J. Flynn, C.E.
- No. 85. THE LUMINIFEROUS AETHER.** By Prof. De Volson Wood.
- No. 86. HANDBOOK OF MINERALOGY; DE-** termination, Description, and Classification of Minerals Found in the United States. By Prof. J. C. Foye. Fifth edition, revised.
- No. 87. TREATISE ON THE THEORY OF THE** Construction of Helicoidal Oblique Arches. By John L. Culley, C.E.
- *No. 88. BEAMS AND GIRDERS.** Practical For-
mulas for their Resistance. By P. H. Philbrick.
- No. 89. MODERN GUN COTTON: ITS MANU-** facture, Properties, and Analyses. By Lieut. John P. Wisser, U.S.A.
- No. 90. ROTARY MOTION AS APPLIED TO** the Gyroscope. By Major J. G. Barnard.
- No. 91. LEVELING: BAROMETRIC, TRIGONO-** metric, and Spirit. By Prof. I. O. Baker. Third edition.
- No. 92. PETROLEUM; ITS PRODUCTION AND** Use. By Boverton Redwood, F.I.C., F.C.S.
- No. 93. RECENT PRACTICE IN THE SANI-** tary Drainage of Buildings. With Memoranda on the Cost of Plumbing Work. Second edition, revised and enlarged. By William Paul Gerhard, C.E.
- No. 94. THE TREATMENT OF SEWAGE.** By Dr. C. Meymott Tidy.
- No. 95. PLATE-GIRDER CONSTRUCTION.** By Isami Hiroi, C.E. Fourth edition, revised.
- No. 96. ALTERNATE-CURRENT MACHINERY.** By Gisbet Kapp, Assoc. M. Inst., C.E.
- No. 97. THE DISPOSAL OF HOUSEHOLD** Wastes. Second edition. By W. Paul Gerhard, Sanitary Engineer.
- No. 98. PRACTICAL DYNAMO-BUILDING FOR** Amateurs. How to Wind for Any Output. By Frederick Walker. Fully illustrated. Third edition.
- No. 99. TRIPLE-EXPANSION ENGINES AND** Engine Trials. By Prof. Osborne Reynolds. Edited with notes, etc., by F. E. Idell, M.E.

- No. 100. HOW TO BECOME AN ENGINEER; or,** The Theoretical and Practical Training necessary in Fitting for the Duties of the Civil Engineer. By Prof. Geo. W. Plympton.
- No. 101. THE SEXTANT, and Other Reflecting** Mathematical Instruments. With Practical Hints for their Adjustment and Use. By F. R. Brainard, U. S. Navy.
- No. 102. THE GALVANIC CIRCUIT INVESTI-**gated Mathematically. By Dr. G. S. Ohm, Berlin, 1827. Translated by William Francis. With Preface and Notes by the Editor, Thomas D. Lockwood. M.I.E.E. Second edition.
- No. 103. THE MICROSCOPICAL EXAMINATION** of Potable Water. With Diagrams. By Geo. W. Rafter. Second edition.
- No. 104. VAN NOSTRAND'S TABLE-BOOK FOR** Civil and Mechanical Engineers. Compiled by Prof. Geo. W. Plympton.
- No. 105. DETERMINANTS.** An Introduction to the Study of, with Examples and Applications. By Prof. G. A. Miller.
- No. 106. COMPRESSED AIR.** Experiments upon the Transmission of Power by Compressed Air in Paris. (Popp's System.) By Prof. A. B. W. Kennedy. The Transmission and Distribution of Power from Central Stations by Compressed Air. By Prof. W. C. Unwin. Edited by F. E. Idell. Third edition.
- No. 107. A GRAPHICAL METHOD FOR SWING** Bridges. A Rational and Easy Graphical Analysis of the Stresses in Ordinary Swing Bridges. With an Introduction on the General Theory of Graphical Statics, with Folding Plates. Second edition. By Benjamin F. La Rue.
- No. 108. SLIDE-VALVE DIAGRAMS.** A French Method for Constructing Slide-valve Diagrams. By Lloyd Bankson, B.S., Assistant Naval Constructor, U. S. Navy. 8 Folding Plates.
- No. 109. THE MEASUREMENT OF ELECTRIC** Currents. Electrical Measuring Instruments. By James Swinburne. Meters for Electrical Energy. By C. H. Wordingham. Edited, with Preface, by T. Commerford Martin. With Folding Plate and Numerous Illustrations.
- No. 110. TRANSITION CURVES.** A Field-book for Engineers, Containing Rules and Tables for Laying out Transition Curves. By Walter G. Fox, C.E. Second edition.

- No. 111. GAS-LIGHTING AND GAS-FITTING.** Specifications and Rules for Gas-piping. Notes on the Advantages of Gas for Cooking and Heating, and Useful Hints to Gas Consumers. Third edition. By Wm. Paul Gerhard, C.E.
- No. 112. A PRIMER ON THE CALCULUS.** By E. Sherman Gould, M. Am. Soc. C.E. Third edition, revised and enlarged.
- No. 113. PHYSICAL PROBLEMS and Their Solution.** By A. Bourgougnon, formerly Assistant at Bellevue Hospital. Second edition.
- No. 114. USE OF THE SLIDE RULE.** By F. A. Halsey, of the "American Machinist." Fourth edition, revised and enlarged.
- No. 115. TRAVERSE TABLE.** Showing the Difference of Latitude and Departure for Distances Between 1 and 100 and for Angles to Quarter Degrees Between 1 Degree and 90 Degrees. (Reprinted from Scribner's Pocket Table Book.) Third edition.
- No. 116. WORM AND SPIRAL GEARING.** Reprinted from "American Machinist." By F. A. Halsey. Second revised and enlarged edition.
- No. 117. PRACTICAL HYDROSTATICS, AND Hydrostatic Formulas.** With Numerous Illustrative Figures and Numerical Examples. By E. Sherman Gould.
- No. 118. TREATMENT OF SEPTIC SEWAGE,** with Diagrams and Figures. By Geo. W. Rafter. Second edition.
- No. 119. LAY-OUT OF CORLISS VALVE GEARS.** With Folding Plates and Diagrams. By Sanford A. Moss, M.S., Ph.D. Reprinted from "The American Machinist," with revisions and additions. Second edition.
- No. 120. ART OF GENERATING GEAR TEETH.** By Howard A. Coombs. With Figures, Diagrams and Folding Plates. Reprinted from the "American Machinist."
- No. 121. ELEMENTS OF GAS ENGINE Design.** Reprint of a Set of Notes accompanying a Course of Lectures delivered at Cornell University in 1902. By Sanford A. Moss. Illustrated.
- No. 122. SHAFT GOVERNORS.** By W. Trinks and C. Housum. Illustrated.
- No. 123. FURNACE DRAFT; ITS PRODUCTION** by Mechanical Methods. A Handy Reference Book, with figures and tables. By William Wallace Christie. Illustrated. Second edition, revised.

No. 124. "SUMNER'S METHOD" FOR FIND-
ing a Ship's Position. Condensed and Improved. By
Rev. G. M. Searle, Ph.D.

No. 125. TABLES FOR THE DETERMINATION
of Common Rocks. By Oliver Bowles, M.A., Instructor
of Geology and Mineralogy, University of Minnesota.

No. 126. PRINCIPLES AND DESIGN OF AERO-
Planes. By Herbert Chatley, B.Sc., Author of "The
Problem of Flight," "Force of the Wind," etc. Second
edition, revised. Illustrated.

No. 127. SUSPENSION BRIDGES AND CANTI-
levers; their Economic Proportions and Limiting Spans.
By D. B. Steinman, C.E., Ph.D., Assistant Professor of
Civil Engineering, University of Idaho.

LT P270
W8

360390

Wisser

UNIVERSITY OF CALIFORNIA LIBRARY

TEXT BOOKS

FOR

Colleges and Technological Institutions.

THEORETICAL MECHANICS.

With an Introduction to the Calculus. Designed as a Text-Book for Technical Schools and Colleges, and for the use of Engineers, Architects, &c. By JULIUS WEISBACH, Ph.D. Translated from the German by ECKLEY B. COXE, A.M., Mining Engineer. One Volume, large 8vo, 1112 pages, 902 Illustrations, Cloth \$6.00. Sheep \$7.50.

The Graphical Statics of Mechanism.

A Guide for the use of Machinists, Architects and Engineers; and also a Text-Book for Technical Schools. By GUSTAV HERMANN, Professor in the Royal Polytechnic School at Aix-la-Chapelle. Translated and Annotated by A. P. SMITH, M.E. Fourth Ed. 12mo, cloth, illus. \$2.00.

Elementary Mechanism.

Text-Book for Students of Mechanical Engineering. By ARTHUR F. WOODS, Assistant Engineer U. S. Navy, Assistant Professor of Mechanical Engineering, Illinois State University, etc., and ALBERT W. STAHL, M.E., Assistant Engineer U. S. Navy, Professor of Mechanical Engineering, Purdue University, La Fayette, Ind., etc. Fourth Edition. 12mo, cloth, illustrated . . . \$2.00.

Elements of Mechanics.

Including Kinematics, Kinetics and Statics. With applications. By Professor T. W. WRIGHT, of Union College. Third Edition, revised. 8vo, cloth, illustrated . \$2.50.

Bowser's Analytic Mechanics.

An Elementary Treatise on Analytic Mechanics. With numerous examples. By EDW. A. BOWSER, LL.D. 12th Edition. 12mo, cloth \$3.00.

Elementary Mechanics, including Hydrostatics and Pneumatics.

By Professor OLIVER J. LODGE. Revised Edition. 12mo, cloth, illustrated \$1.50.

Applied Mechanics.

A Treatise for the Use of Students who have time to Work Experimental, Numerical, and Graphical Exercises, Illustrating the Subject. By JOHN PERRY, M.E., D.Sc., F.R.S. 8vo, cloth \$2.50.